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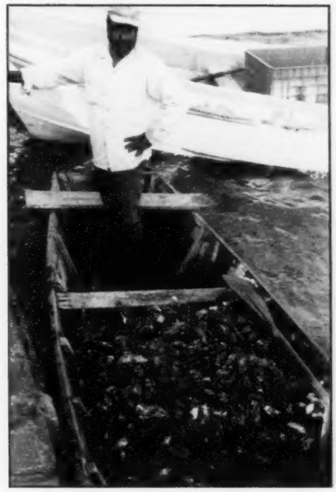

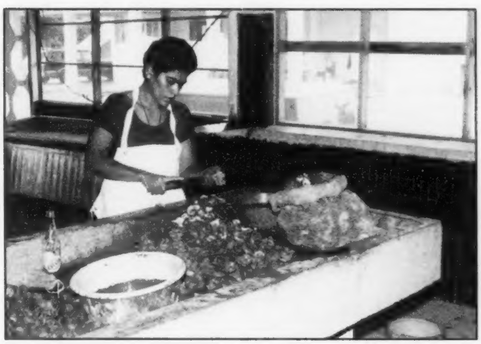

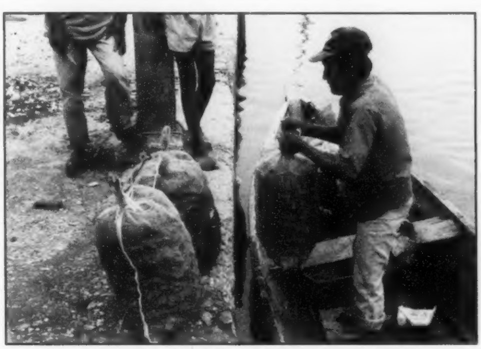

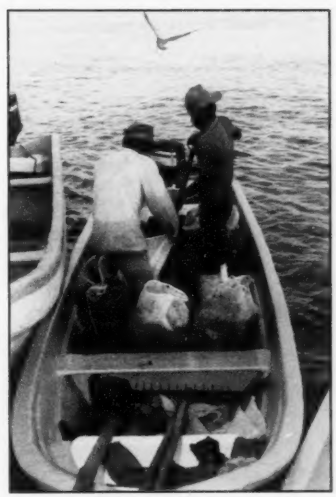

The Oyster Industry of Eastern Mexico

Marine Fisheries REVIEW

W. L. Hobart, Editor
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On the cover: Scenes from the oyster industry of eastern Mexico. Photographs by C. MacKenzie, Jr.

Articles

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The Oyster Industry of Eastern Mexico

CLYDE L. MacKENZIE, Jr. and ARMANDO T. WAKIDA-KUSUNOKI

Introduction

Mexico has an oyster industry of substantial size, ranking about sixth in the world. In 1993, among the top ten oyster producers, Korea, Japan, the United States, China, and France ranked ahead of Mexico, while the Philippines, Australia, Canada, and New Zealand trailed it (Fig. 1). On its east coast, the species landed is the eastern oyster, *Crassostrea virginica,* while on its west coast *C. corteziensis*, *C. iridescens*, and the Pacific oyster, *C. gigas*, are landed. During the last 10–15 years, annual production often was at least 50,000 t of shelled oysters, or nearly 1.5 million bushels (Anonymous, 1995), with the great preponderance (90%) coming from a series of lagoons connecting with the Gulf of Mexico along the east coast (Fig. 2) and the remainder produced on the west coast.

On the east coast, fishermen in most lagoons intersperse oystering with catching shrimp and fish, though oystering is economically most important (Galvan[1]). The oysters are harvested with tongs and by hand. All the east

[1] Juan Rogelio Galvan Utrera, Chief, Aquaculture Department, SEMARNAP, Villahermosa, Tabasco, Mex.

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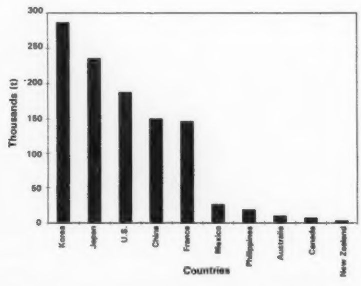

Figure 1.—Oyster production of the ten leading countries of the world in 1993 (FAO, 1993).

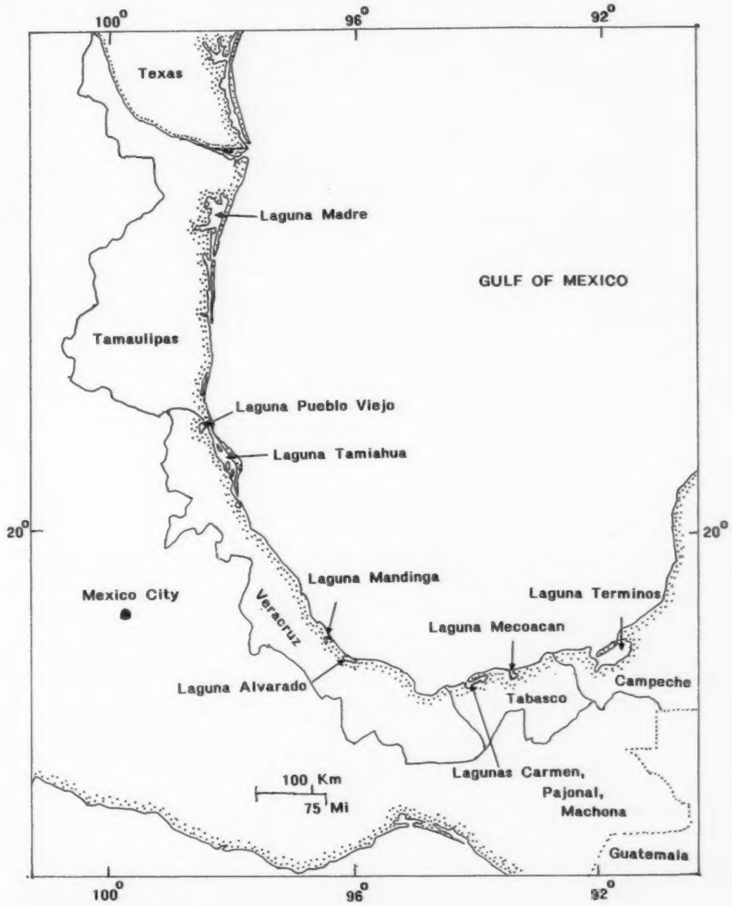

Figure 2.—The east coast of Mexico with the principal oystering lagoons identified.

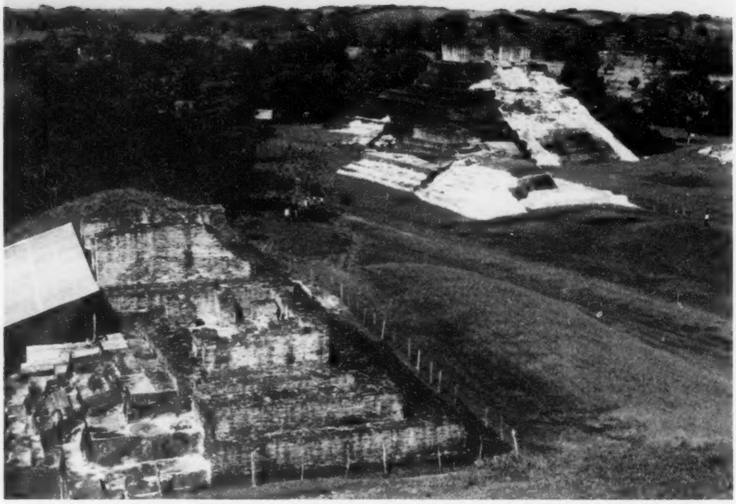

Figure 3.—Mayan ruins at Comalcalco, Tabasco. Oyster shells were used in the cementing materials to bind the building blocks together.

coast production is consumed in various towns and cities within Mexico, where a long-standing tradition, mostly among men, exists for eating oysters. At least 90% are prepared in cocktails, while some are served raw on the half-shell, and small quantities are cooked. Oysters are eaten year-round, but fewer are eaten in the warmest months when some beds are closed to allow oyster seed to grow. The strongest demand period is during the 40 days of Lent, February–April.

Little has been written in international journals about the Mexican oyster industry, and it is little known outside of Mexico. This paper describes the oyster boats and gears, and harvesting, culture, processing, and marketing methods, and consumption of oysters in eastern Mexico. Most of the information was obtained on surveys during 8–17 November 1996 and 29 January to 5 February 1997. They covered the full extent of the oyster-producing region from Laguna Madre just south of the U.S. border to Laguna de Terminos in the southeast, and included interviews with about 50 government officials, fishermen, processors, trucking owners, managers of cooperatives, and restaurant owners, as well as observation and photography. Prices are reported in U.S. dollars.

Early Uses of Oyster Shells

Several centuries ago, the Mayans living near the southern coast of the Gulf of Mexico used ground shells of oysters and other mollusks to make lime and mixed it with sand as material to construct their homes. In addition, they used oyster shells as one of the binding materials to hold together large blocks in constructing many of their large temples and other structures. For example, the Mayan ruins at Comalcalco in Tabasco are constructed with the use of oyster shells (Fig. 3). In the early years of this century, oyster shells were used to fill hollows in the ground when homes were constructed, and the shells were burned to make lime for painting houses and trees (Rodriguez[2]). Few shells were returned to the oyster beds as cultch for oyster larvae. Shell mounds left by ancient Indians (middens) are rare or do not exist in eastern Mexico.

Oyster Landing Statistics

The Mexican government collects statistics on landings of all its fishery products. In the 11 years from 1985 to 1995, annual oyster production in eastern Mexico ranged from 22,821 t to 52,131 t, with an average of 37,548 t or about 1 million bushels of shelled oysters. Production for the 4-year period, 1992–95, with an average of 28,259 t/year was about one-third less than the average of 44,482 t/year for the previous 7 years (Fig. 4). Production dropped mainly because the demand for oysters fell, while the supplies in the estuaries did not decline except in 1993 when the flatworm, *Stylochus* sp., population exploded and the worms killed many oysters (Rodriguez[2]).

East coast production comes from four states. The State of Veracruz usually led the other three with production mainly from Lagunas Pueblo Viejo and Tamiahua and a small amount from Lagunas Mandinga and Alvarado. The second leading State in production was Tabasco, with oysters coming mainly from Lagunas El Carmen, Pajonal, Machona, and Mecoacan. The States of Tamaulipas, with most production from Laguna Madre, and Campeche, with most production from Laguna de Terminos, combined to produce about one-sixth as many oysters as the total of the other two states (Fig. 5).

Oysters are landed in every month, but slightly more than twice as many are produced in the six cooler months (December through May when production averages 3,655 t/month) than in the six warmer months (June through November when production averages 1,649 t/month)(Fig. 6). The highest production is in April and May when oysters are the largest (Corripio[3]). The monthly production data include both Atlantic and Pacific coasts. A reason for less production in the warm months is that oystering in some lagoons is closed by the Federal Government for periods of 2.5–3 months then.

The oyster species *Crassostrea corteziensis*, *C. iridescens*, and *C. gigas* are landed in 9 of the 11 states on the Pacific coast. In recent years, the States of Baja California, Baja California Sur, Guerrero, Sinaloa, and Sonora have been the leading Pacific coast producers (Anonymous, 1995).

[2] Ruben Rodriguez Navarro, Chief of Aquaculture Department, SEMARNAP, Juan De La Luz Enriquez #8, Colonia Adolfo Ruiz Cortinez, Tuxpan, Veracruz, Mex.

[3] Ernesto Corripio, Chief of Cooperative, Tuxpan, Veracruz, Mex.

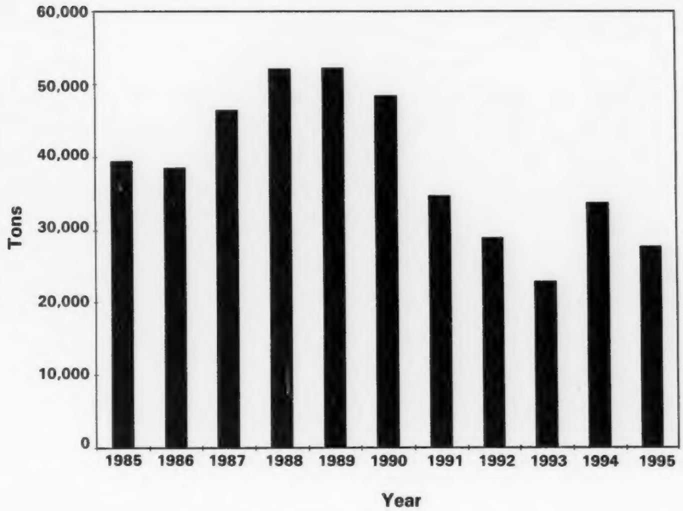

Figure 4.—Annual oyster landings in eastern Mexico, 1985–1995 (Anonymous, 1995).

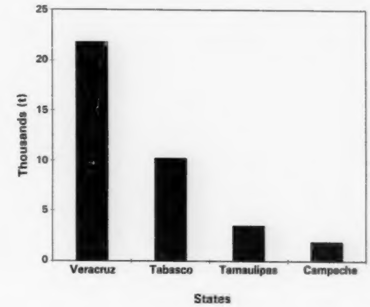

Figure 5.—Comparison of oyster landings from each of four states of eastern Mexico, average for 1985–95 (Anonymous, 1995).

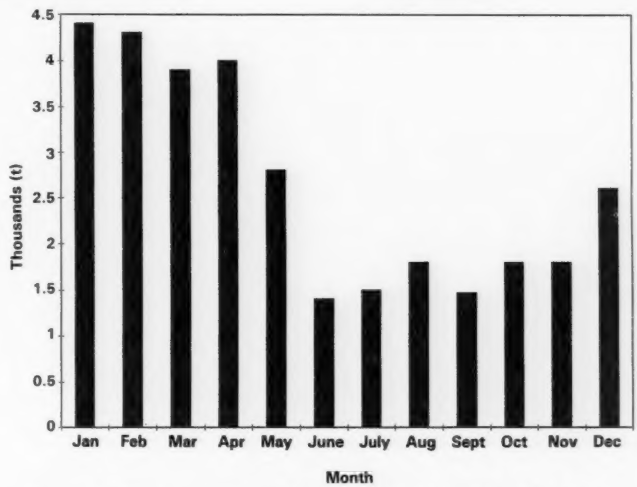

Figure 6.—Mexican oyster landings by month (Atlantic and Pacific coasts combined)(Anonymous, 1995).

The Oyster Lagoons

Oysters are present in nearly every lagoon along the east coast from Laguna Madre to Laguna de Terminos. The lagoons are relatively large but shallow. Total lengths (and depths where most oysters are harvested) of the major oyster-producing lagoons from north to south are: Laguna Madre, 220 km (40 cm–1.5 m); Laguna Pueblo Viejo, 15 km (1–1.8 m); Laguna Tamiahua, 107 km (1.5–3 m)(Fig. 7); Laguna El Carmen, 15 km (40 cm–2 m); Laguna Machona, 14 km (40 cm–2 m); Laguna Mecoacan, 11 km (40 cm–2 m)(Fig. 8); and Laguna de Terminos, 77 km (40–60 cm)(Fig. 9). Between them lie several smaller estuaries where fishermen harvest oysters, and there are 1–2 estuaries containing oysters that are too far from population centers for harvesting.

In the past, the openings in the sand bars between Laguna Madre and the Gulf of Mexico closed, and the lagoon became a saline lake. The Federal Government had to take actions to reopen them (Hildebrand[4]).

The salinities are 31–34‰ in Laguna Madre, 18–21‰ in Laguna Tamiahua, and about 23‰ in Laguna de Terminos (Yanez-Arancibia et al., 1985). Laguna El Carmen has had a history of becoming too fresh for oysters during extended periods of heavy rainfall (Hildebrand[4]). The oysters from Laguna Tamiahua with its moderate salinity may have the best flavor of those along the east coast (Ramirez[5]). In Lagunas El Carmen, Pajonal, and Machona, the salinity ranges from 10–30‰ during the dry season and 0 (near river mouths) to 25‰ during the wet season, while the average annual temperature is 30°C (Antoli and Garcia-Cubas, 1985). Temperatures range from 20°–32°C in Laguna de Terminos (Amezcua-Linares and Yanez-Arancibia, 1980; Alvarez Guillen et al., 1985). The range of tide in the lagoons is small. The maximum is about 50 cm.

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[4] Henry Hildebrand, Professor Emeritus, University of Corpus Christi, Tex.

[5] Ricardo Ramirez Mendoza, Technician, SEMARNAP, La Laja, Veracruz, Mex.

The oyster beds occupy relatively small areas in most lagoons. Perhaps the smallest percentage of bed area to lagoon area is in Laguna de Terminos where the oyster beds occupy about 1% of its area. At the other extreme are Lagunas El Carmen, Pajonal, and Machona, where the beds occupy about 10% of their areas; the bottom between the beds is muddy (Galvan[1]). The bottom of sections of some lagoons such as Laguna Madre is hard sand covered in some areas with tiny clam shells.

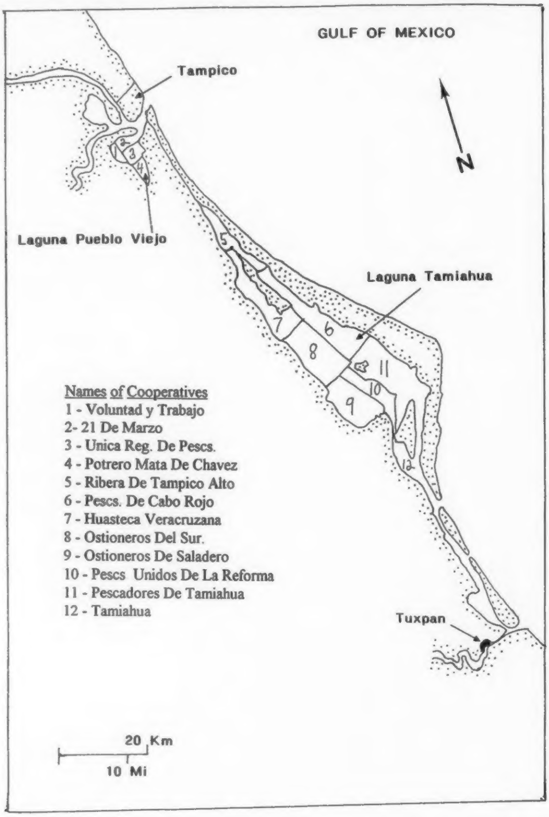

Figure 7.—Lagunas Pueblo Viejo and Tamiahua showing the areas where fishermen belonging to individual oyster cooperatives harvest oysters.

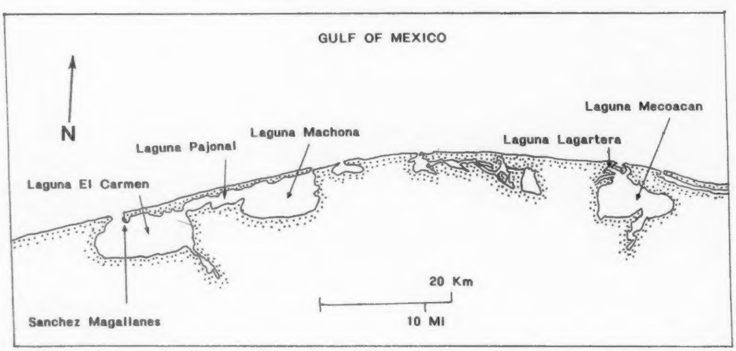

Figure 8.—The principal oystering lagoons in the State of Tabasco. Oyster beds occupy about 10% of their areas.

Oyster Biology and Ecology

The eastern oyster (Fig. 10) grows in clusters and, from Laguna Madre southward through at least Laguna Tamiahua, in two forms. A relatively long, narrow form grows on soft bottoms and locally is called a "huarache" (shoe) or "lengua de vaca" (cow tongue), while a more oval form, similar to most oysters grown in the estuaries of northeastern United States, grows on hard bottom commonly covered with tiny shells and is called a "bola" (ball)(Fig. 11). The two forms can be present on the same oyster cluster. The huaraches lie against the bottom, whereas the bolas are attached to the top shells of the huaraches. The huaraches, which tend to grow larger than the bolas, sometimes are used in cooking. Nearly all oysters are bolas in Tabasco (Cruz[6]). Some Tabasco oysters might take the form of huaraches if they could grow to larger sizes.

Abundant oyster spatfall occurs every year. In the Tabasco lagoons, there are two peaks of setting, in March–April and September–October (Galvan[1]).

The oysters grow to market size within 6 to 12 months in all lagoons (Galvan[1]; Hernandez[7]). In Laguna Madre, huaraches grow to 13 cm and bolas to 10 cm in less than a year. In Tabasco, oysters grow about 1 cm/month and are 70–75 mm long within 7.5 months. Oysters grow faster in winter than summer (Galvan[1]). The fishermen retain oysters at least 70–75 mm long for sale.

Oysters have several animal pests. They include the flatworm, *Stylochus* sp., which when abundant can kill large numbers of oysters in Laguna Madre, Laguna Pueblo Viejo, and other lagoons, but they usually do not cause substantial mortalities. A minor preda-

[6] Alejandro Cruz Diaz, Fisherman, "Los Tamarindos" cooperative, Ciudad Del Carmen, Campeche, Mex.

[7] Jose Hernandez, Fisherman, Muscatel, Tamaulipas, Mex.

tor is the Gulf oyster drill, *Urosalpinx perrugata*. The shells of live oysters are hosts of the mud blister forming worm, *Polydora* sp., and most shells have some black areas on their inside surface caused by the worm. Animal associates attached to oysters in every lagoon include barnacles and the mussel, *Brachidontes* sp. In February 1997, the mussels were so abundant on oysters in Laguna Lagartera the oysters had the shape of balls. In the past, the noncommercial oyster, *Ostrea equestrus*, had become so abundant on *C. virginica* in some lagoons the *C. virginica* were difficult to handle (Hildebrand[4]).

In Tabasco, the oyster predators include the boring snails, *Melongena melongena* and *Thais haemostoma;* blue crabs, *Callinectes sapidus;* and flatworms (Garrido and Utrera, 1987). Competitors of oyster spat on shells include barnacles, *Balanus* sp.; slipper shells, *Crepidula* sp.; bryozoa, *Bowerbankia* sp. and *Schizoporella* sp.; mussels; and the sponge, *Cliona* sp. A species of red sponge occurs in the Tabasco lagoons. The fishermen related that oysters do well in areas where this sponge grows (Galvan[1]).

The oyster pathogen known as Dermo, *Perkinsus marinus,* is highly prevalent in the Tabasco lagoons (Burreson et al., 1994). The oysters die at about 7–8 cm and Dermo is the likely cause of the mortality. The oysters also die after 1 year in all the other lagoons from Laguna Pueblo Viejo through Laguna de Terminos (Galvan[1]). Dermo probably causes the mortalities throughout this range. A survey of Dermo over the entire range of oysters in eastern Mexico has not been reported.

Small quantities of mangrove oysters, *C. rhizophorae*, are also present (Anonymous, 1996), but they are too small for harvesting. Descriptions of them in Mexico were unavailable.

Public Health Problems

Public health regarding oysters is a concern. Human habitation is relatively sparse on the shores of most lagoons, and most oyster harvesting beds are far distant from population centers, but sewage treatment is absent or rudimentary. Some sections of lagoons have low concentrations of coliform bacteria. The most critical problems are in Laguna

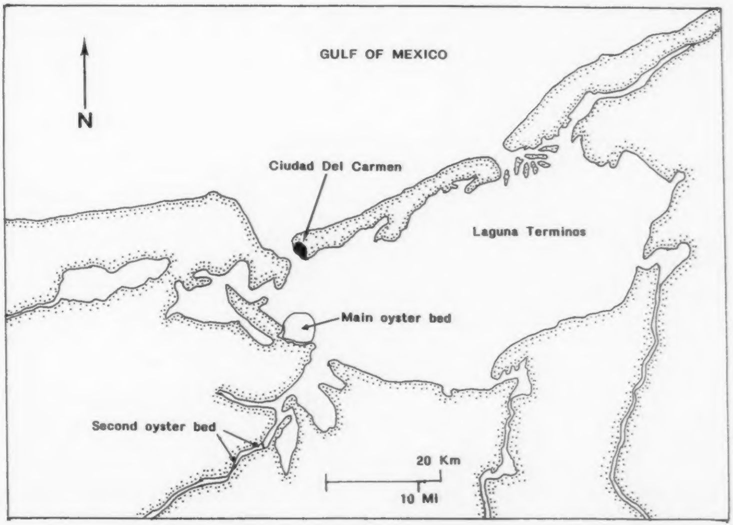

Figure 9.—The locations of the two commercial oyster beds in the Laguna de Terminos region.

Figure 10.—An oyster from Laguna Madre with its upper valve removed.

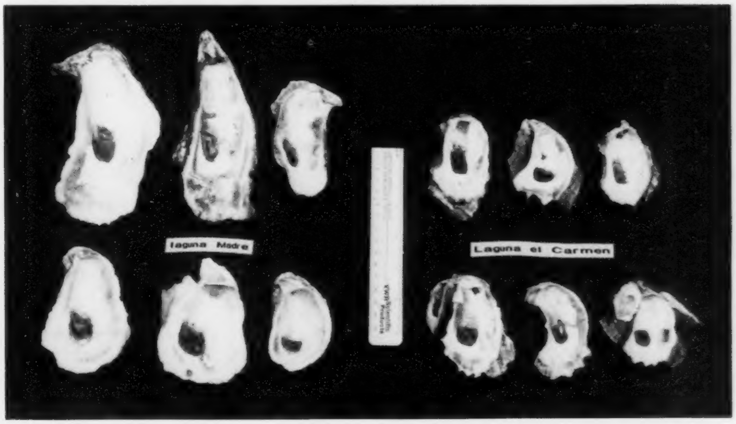

Figure 11.—At the left, six oyster shells from Laguna Madre. The upper three are "huaraches," while the bottom three are "bolas." At the right, six shells of market-sized oysters from Laguna El Carmen. The ruler between the shells is 15 cm (6 inches) long.

Pueblo Viejo and Laguna Alvarado, which receive effluents from the city of Tampico and the town of Alvarado, respectively. In this century, groups of people occasionally have become ill from eating oysters and, in recent years, such an event was publicized by the media (newspapers, radio, and television), leading to a temporary drop in demand for oysters.

Construction of sewage-treatment plants to reduce the coliforms has been considered too expensive to finance. The Federal Government has been attempting to support the industry by constructing better processing plants, issuing higher standards for shucking and handling oysters, and is considering depurating oysters before sale. Federal Government health authorities check lagoon waters and oyster meats in the plants at least once every 4 months to determine whether they meet standards for human consumption. A rapid transport of oysters from the beds to markets and the oysters being in ice on the trucks undoubtedly prevents bacteria from multiplying substantially.

Oil pollution was a problem in the lagoons of Tabasco in the 1980's. Oil drilling platforms were installed in the Gulf of Mexico offshore of the lagoons. Pipes on the platforms sometimes broke and northerly winds blew oil slicks into the lagoons contaminating the oysters to a small extent. Such contamination has rarely occurred in the 1990's and has not been serious (Galvan[1]). Some fishermen blamed any oyster mortalities on the oil, but Burreson et al. (1994) suggest that Dermo was the actual cause.

Red tides appear about once every 2 years in northern estuaries, according to fishermen (Perez[8]). The tides usually persist for 2–3 weeks, and the Federal Government suspends harvesting for several weeks to protect public health.

Fishermen's Cooperatives

Most fishermen belong to cooperatives where they sell their oysters and other marine species. The cooperatives own the buildings where the oysters are processed and sold. Separate lagoons have from one cooperative, such as in Laguna Alvarado with 81 members and Laguna de Terminos with 56 members, to several, such as in Laguna Madre, Laguna Puerto Viejo, Laguna Tamiahua (with eight), and the lagoons of Tabasco. Some cooperatives have at least 200 members. In certain lagoons, fishermen can harvest oysters anywhere, but in others all sections of bottom are under individual cooperative control and only cooperative members can harvest oysters in them. Individual cooperative control over bottoms is practiced in Lagunas Puerto Viejo, Tamiahua (Fig. 7), and in Laguna de Terminos, but not in Lagunas Madre, El Carmen, Pajonal, and Machona (Galvan[1]).

When a fisherman sells a product to his cooperative, it takes 8% of the selling price and the buyer pays 10% of the purchase price to the cooperative. The total money is paid to the Federal Government as a tax.

The Fishermen

The oyster fishermen, all of whom are males, live in small communities on the shores of the lagoons. Most walk to their boats and the cooperatives. They have low incomes (Galvan[1]). A common saying around the oystering areas is "Fishermen go out to harvest oysters to make enough money to purchase some food to eat." The tonger in a boat pays the worker he has hired to cull his catch about $3.50 a day.

In the mid-1990's, there were 350 fishermen in Laguna Pueblo Viejo; nearly all were oystering on good days when there was a demand for oysters (Anonymous, 1996). In Lagunas El Carmen, Pajonal, and Machona combined, about 150 men harvested oysters on typical good days (Galvan[1]), and 50 did so in Laguna de Terminos (Cruz[6]). Similar statistics for the other lagoons were not available.

Harvesting Gear and Methods

Fishermen harvest the oysters with tongs from boats (Fig. 12, 13) or by hand while wading (Fig. 14). In Lagunas Pueblo Viejo and Tamiahua, most harvesting is with tongs, and in Lagunas El Carmen, Pajonal, and Machona, nearly all harvesting is with tongs (Galvan[1]). The harvesting vessels include narrow wooden boats, 4.9–6.1 m long, and fiberglass boats, about 7.6 m long, and in Tabasco some dugout canoes as well. The dugouts, once common, are becoming scarcer because few large trees remain with which to make them. All vessels are propelled by outboard motors ranging from 15 to 45 hp. A new fiberglass boat costs $1,500 and a new 45-hp outboard motor costs $3,500 (Rodriguez[9]). The tongs and cross-piece at the bottom are made of wood; most are made of mahogany, *Swietenia mahogani*. Long nails are driven into the cross-piece to act as teeth. A pair of tongs costs $12.90–$25.80 depending on their length which ranges from 2.4 to 4.6 m (Galvan[1]). Heavy old knives are used to cull the oyster clusters (Fig. 15).

Individual fishermen usually harvest oysters 3–4 days a week during the open season, but harvesting can be as infrequent as 1 day a week when the market demand is poor. They always harvest them on orders from the cooperatives which in turn have orders from buyers. The government insists that at least two men are present in each boat, one to harvest the oysters and one to cull and return shells, some containing seed, to the beds. In most lagoons, when there are no orders for oysters, the fishermen seek finfish or shrimp. Laguna Terminos is one exception where oyster fishermen seek only oysters. Boats with two men typically harvest 3–4 sacks in 8 h of harvesting. Each sack contains about 450 culled oysters which weigh 35 kg. A boat with four men (two tongers and two cullers) harvests about 7 sacks. In Laguna Madre, at least one crew of three tongers harvests 27–33 sacks (12,000 to 15,000 culled oysters) per day (Rodriguez[9]).

Fishermen do most hand harvesting at wading depths, less than 1 m. To protect against cuts, they wear short boots or sandals and gloves. Most fishermen put the oysters in floating containers when harvesting. In Laguna Madre, the fishermen use large galvanized wash-

[8] Jose Julio Perez, Fisherman, Carboneras, Tamaulipas, Mex.

[9] Severo Rodriguez, Fisherman, Carboneras, Tamaulipas, Mex.

Figure 12.—(Left) A fisherman with his tongs, dugout canoe, and some oysters at the shore of the town of Sanchez Magallanes, Laguna El Carmen.

Figure 13.—(Above) Fisherman tonging oysters in Laguna Machona with helper culling his oysters.

Figure 14.—(Below left) Harvesting oysters by hand and holding them in a dugout canoe, Laguna Lagartera.

Figure 15.—(Below right) Using part of an old machete as a culling iron.

ing tubs, while in the south in Lagunas Lagartera, Mecoacan, and de Terminos, they use plastic and wooden boxes with floats attached and holding about a bushel (Fig. 16).

In Laguna Madre, many fishermen gather oysters by hand-picking when the water is warm enough to permit wading. This is all months except December, January, and February, when they harvest with tongs. About one-third of the oysters in Laguna Pueblo Viejo are harvested by hand-picking (Corripio[3]). In Laguna Tamiahua, a crew of three, with two in the water hand-picking and one in their boat culling, can harvest as many as 11 sacks of oysters in 6 h, while a crew of two, with one picking and one culling, can harvest about 6 sacks in 8 h.

Hand harvesting is the only method used in the small lagoons of Mandinga and Alvarado. In Mandinga, fishermen, who range in age from 14 to 70 (Gallegos[10]), usually dive for oysters about 4 hr a day. They wear face masks but not fins. They obtain about 85% of the oysters in water 1.5–2 m deep and the remainder in waters up to 4 m deep, by making shallow dives to see the oyster clusters on the bottom. When oysters are abundant, a fisherman can get as many as 25–30 oysters in clusters on a dive. The divers put the oysters directly into their boats. A typical harvest for a two-man crew is 5.5–6.7 sacks (2,500–3,000 oysters) per day. In Laguna Alvarado, the fishermen open their oysters on the beds, put the meats in cans, and return the shells to the beds. They later wash the meats ashore when they pack them (Hernandez[11]).

In Laguna de Terminos, where oysters are harvested only by hand-picking, 17–20 fishermen ride from the city of Ciudad Del Carmen to the oyster beds, a 1-h run, in each of three 7.6 m boats. Once there, they wade onto an oyster bed, pick up oysters, cull them, and put them into floating wooden boxes that each hold about 540 oysters

[10] Ing. Pesq. Horacio Gallegos Salledo, Calle Francisco Villa Lotes 8 and 9 Int. 201, Colonia Flores Magon, Bola Del Rio, Veracruz, Mex.

[11] Hermilo Hernandez Sosa, Fisherman, Arbolillo Municipio de Alvarado, Veracruz, Mex.

Figure 16.—Tubs with floats used to hold oysters while fishermen hand-pick them. In tub at right is face mask fishermen wear when harvesting at depths beyond about 1 m.

or about a bushel. When the boxes are full, they put them on the boat. Each man has a quota of 2,700 oysters (5 boxes) a day of harvesting. Each boat returns to the cooperative oyster house in Ciudad Del Carmen with 85–100 boxes of oysters. The men usually work 8-h days from 4 a.m. to 12 noon. They shuck their oysters in the cooperative plant in the afternoons on harvesting days when the demand for them is high; however, they may shuck them the following morning instead of harvesting if the demand is low (Cruz[6]).

Oyster Culture

Oyster culture has to be inexpensive because the fishermen have low incomes (Galvan[1]). The principal oyster culture method practiced by the fishermen is returning nearly all shells to the beds after the oysters are shucked, an action mandated and closely overseen by the Federal Government since 1976. No more than 20% of oysters can be sold in the shell because that shell rarely is returned to the beds. If a cooperative sells more than 20% of its oysters in the shell, it has to obtain shells from another area and spread them to make up the loss (Rodriguez[5]). The government forbids cooperatives to sell shells for other purposes, such as to the poultry industry.

The hand harvesters from Lagunas Mandinga to de Terminos work the oyster beds in a similar way, which ensures a crop will always be available for harvesting. The crop will also consist of oysters of about uniform size. Over a few months, the fishermen harvest nearly all the oysters on a bed and then spread shells, which they have stored ashore, over it to start another oyster crop (Fig. 17, 18). They then move to the next bed of oysters, which they had shelled several months previously, and repeat the procedure (Cruz[6]; Gallegos[10]).

Government officials in addition encourage some cooperatives to practice hanging oyster culture. For example, in the Lagunas El Carmen and Machona, Tabasco, cooperatives are hanging necklaces of oyster shells in water 1–1.5 m deep. Fishermen store shells (Fig. 19) and then drill holes in their centers and string them onto monofilament lines about 50 cm long; each necklace has 17 pairs of shells (Fig. 20). The necklaces are hung from horizontal wooden poles set on the tops of cement posts anchored in the bottom about 4 m apart; about 15 pairs of necklaces are set on each beam (Fig. 21). Each farm unit has about 1,500 posts. In 1996, one cooperative farm in Laguna El Carmen set out 80,000 necklaces. Most shells with oyster seed are spread on the beds, while the rest remain on the strings until ready to be harvested. In the two lagoons, about 5% of available stored shells are put onto the necklaces while the remainder are spread on the beds.

Figure 17.—Cooperative members spreading shells over a bed where they had harvested all the oysters, to start another crop.

Figure 18.—Oysterman spreading oyster shells over bed of his cooperative.

Extremely large shells are used as ash trays.

In Laguna Mandinga, Veracruz, some cooperatives are engaged in a new project that involves placing burlap bags, which have been soaked in a water slurry of cement, sand, and a small amount of ground oyster shell and then air-dried (Fig. 22), in the estuary to collect oyster sets. The spat are removed when about 2 cm long and are spread on hard bottoms. In 8 months after setting, the oysters grow to a length of about 8 cm, a perfect market size (Gallegos[10]; Chavez[12]).

[12] Jesus Chavez Campos, Cooperative secretary, Pescadores de Mandinga Cooperative, Veracruz, Mex.

Local Oyster Consumption

Nearly all fishermen take some oysters home to eat. Their families eat oysters from one to four times a week. In one village bordering on Laguna Madre, the local people spread shells on a nearby bottom to have a supply of oysters to eat themselves. Oysters are

Figure 19.—Stored oyster shells near shore of Laguna El Carmen to be used as cultch for oyster larvae.

Figure 21.—Beams supported by cement posts holding necklaces of shells, Laguna El Carmen.

Figure 20.—Necklaces of oyster shells in Sanchez Magallanes, Tabasco, to be suspended as cultch for oyster larvae in Laguna El Carmen. They are held by Juan Galvan Utrera (left), Chief, Aquaculture Department of SEMARNAP, Villahermosa, Tabasco, and Armando Wakida-Kusunoki (right), junior author of this paper.

Figure 22.—Air-drying bags which were dipped into a water slurry of cement-sand-ground oyster shell. They will be suspended in Laguna Mandinga, Veracruz, as cultch for oyster larvae.

served in cocktails with tomato, onion, chile, and oil, or with lemon, salt, ketchup, hot pepper, and onion; or on the half-shell. Oysters are also cooked in various ways: 1) with oil, onion, tomato, and hot sauce; 2) in a soup with blue crabs, shrimp, and clams; or 3) breaded in corn meal and fried (Perez[8]).

Processing Oysters

At least 90% of harvested oysters are shucked and sold as meats. The oysters usually are harvested, shucked, and packed in the same day when the demand is strong. Fishermen land the oysters in the late morning and they are opened and packed by 6 p.m. (Corripio[3]). Otherwise, they are held over for shucking until the following day. The processing buildings are in towns on the shores of lagoons where oysters are harvested. Nearly all buildings have cement floors, walls, and tables, glass windows, and screen doors, while some have roofs but no walls (Fig. 23). The oyster knives are similar to the common wood-handled oyster knife used in the U.S., but they have a wider steel blade (Fig. 24). Most are made by local tradesmen from discarded machetes and then sold for about $3.85 apiece. In the States of Tamaulipas and Veracruz, the knives have square handles, while those in Tabasco and Campeche have round handles. The shuckers include men, women, and children as young as seven, all of whom work on a piece-work basis, but fishermen often open their own oysters. Shuckers are paid from $1.42–$1.55/1,000 oysters opened (Lara[13]). Each person usually opens from 2,000–5,000 oysters/day, the most experienced people opening the largest numbers (Galvan[1]).

The shuckers, usually wearing a white cap, white apron, and white boots as mandated by the Federal Government, stand next to the tables in cooperative buildings and shuck the oysters into plastic bowls. In most cooperatives, workers empty the meats into a large cement tank of freshwater and then scoop them out with colanders of measured volumes, such as a liter, and

[13] Rocio Lara Lara, Oyster shucker, Sanchez Magallanes, Tabasco, Mex.

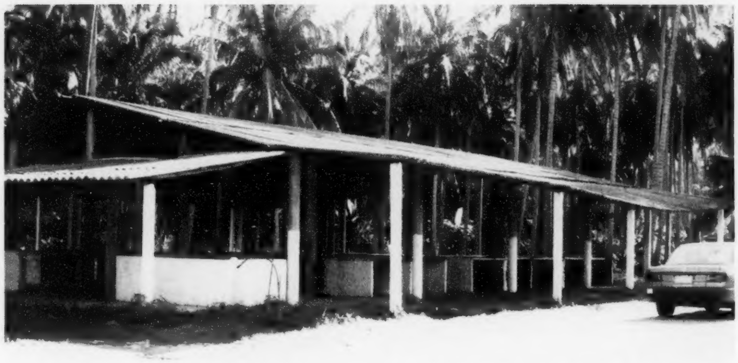

Figure 23.—A cooperative building with no walls where oysters are shucked and packed on the shore of Laguna Lagartera, Tabasco.

empty them into clear plastic bags. The bagged meats are free of mud and have few shell particles. The workers then dip the bags into freshwater to fill them and tie a tight knot in their ends to seal them (Fig. 25). The bags contain about half oyster meats and half water. Buyers want freshwater in the bags so the meats will swell (Galvan[1]).

The quantity of oysters in bags varies in different places and times, and it is based on directives from buyers. The smallest quantity observed was in Ciudad Del Carmen where 100 oysters were hand-counted into each bag. The largest quantities are 3–4 l.

Oyster handling at the various cooperatives appeared to be the most sanitary in Ciudad Del Carmen. The shuckers wore gauze face masks, besides white aprons, white caps, and white boots (Fig. 26). Instead of emptying meats into large cement tanks, workers poured them into 8-l plastic pans containing freshwater continuously changed from faucets of running water. The meats were swirled around by hand to free them of mud and shell particles before they were counted and packed.

Small quantities of oysters are also shucked out-of-doors on the shores of lagoons, such as Mecoacan, during the morning they are harvested (Fig. 27). The meats are sold in plastic bags on the same day along busy roadways which run past the lagoons (Fig. 28).

The remaining oysters are sold in the shell. The fishermen pack them in burlap bags and set each bag on a scale to ensure it weighs 35–36 kg (Fig. 29), and then a crew loads them onto a truck for delivery.

Markets and Marketing

Oyster meats and shelled oysters are sold in most Mexican population centers, and the largest market is Mexico City with a population of about 17 million. East coast oysters are sold in cities such as Cancun, Coatzacoalcos, San Luis Potosi, Puebla, Guadalajara, and Merida, and in most all states. Buyers send their trucks to the various cooperatives on the coast to pick up and deliver the oysters they had ordered. At the cooperatives, the trucks usually are waiting to load the oysters as soon as they are packed in the bags. If not, the bags of meats are placed in a cold room temporarily. The bags of meats are packed in a bed of crushed ice on the trucks (Fig. 30) and driven immediately to an inland city. The trip to Mexico City takes 7 h from Laguna Tamiahua and 11 h from Laguna Machona (Galvan[1]). Once there, they are taken immediately to fish markets and restaurants. The length of time from oysters leaving the beds to reaching the markets commonly is within 24 h.

A truck must have a load of at least 100 sacks of shelled oysters for the owner to make the trip from the coast to an inland city worthwhile. A full load for a typical 3-ton truck is 100–120 sacks. In 1996, a cooperative in Tamiahua paid fishermen $6.45/sack of oysters, buyers paid the cooperative $7.75/

Figure 24.—(Above) A typical knife used to shuck oysters in eastern Mexico.

Figure 25.—(Right) Workers partially filling plastic bags with oyster meats, shore of Laguna Machona. One worker is preparing to tie knot in top of bag to seal it. The bags usually contain more water than is shown here.

Figure 26.—Oyster shuckers in packing plant in Ciudad Del Carmen, Campeche; note face masks, and white caps, aprons, and boots.

Figure 27.—Shucking oysters on the shore of Laguna Mecoacan. The oysters were harvested and will be on sale during the same day.

sack, and retailers in Mexico City paid the buyers $10.32/sack. Some restaurants in Mexico City hold oysters in saltwater tanks while selling them.

Oyster meats in plastic bags are sold in fish markets (Fig. 31) and outdoor markets wherever fish are sold. The quantity of meats usually ranges from 100 to 1,000/bag, and their prices vary among outlets. In 1996, in Laguna El Carmen, the cooperative paid fishermen $4.64/bag of 1,000 meats and sold them for $6.19; a fish market in Coatzacoalcos sold them for $10.32. Other prices in the same fish market were: $1.29 for 70 oysters, $2.58 for 250 oysters of mixed sizes and for 500 small oysters, and $3.87 for 200 large oysters. In a fish market in Ciudad Del Carmen, prices for similar bags were: $1.29 for 100 small oysters, $1.81 for 100 large oysters, $3.35 for 200 oysters, and $4.90 for 800 oysters. In an outdoor market in the town of Paraiso, bags of 200 oysters sold for $1.29 each. Schoolboys sold bags of 200 oyster meats each on the side of a busy road on a Sunday morning for $1.29 each.

A small restaurant in the city of Naranjos sold oyster cocktails and oysters on the half-shell. The restaurant bought small oyster meats with 1,000/bag and large meats with 500/bag for $2.58/bag. It charged $2.06 for a cocktail with small oysters, $3.23 for a cocktail with large oysters, and $3.23 for a serving of 25 oysters of the half-shell. Its customers, as did at least one restaurant in Mexico, preferred oysters from Tamiahua Lagoon (salinity 18–21‰) to those from Laguna Madre (salinity about 32‰) because they had a

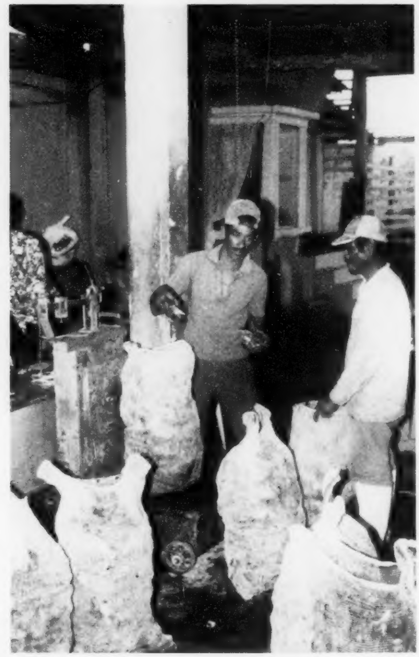

Figure 28.—(Above) Selling oyster meats on a roadside near Laguna Mecoacan.

Figure 29.—(Right) Weighing oysters at a cooperative in Tuxpan, Veracruz. The bags must weigh a minimum of 35 kilos (77 pounds).

Figure 30.—(Below right) Crew at shore of Laguna Machona packing bags of oyster meats in bed of crushed ice in truck bound for an inland city.

better flavor. This restaurant ordinarily sold 5–6 bags of oyster meats in cocktails and some oysters on the half-shell every day (Almanda[14]). An upscale restaurant in Ciudad Del Carmen sold oyster cocktails with 15 oysters for $1.93, with 25 oysters for $3.87, and a jumbo cocktail for $5.80 (Fig. 32). An inexpensive restaurant in the city sold cocktails for $1.29 each. Another restaurant sold oyster soup for $1.29/bowl.

When the Mexican economy is good and people in the cities have spare money, oysters sales are brisk. When it is poor, sales are slow.

Recent Developments

The Federal Government is concerned about the sanitary conditions under which oysters are handled in cooperative processing plants. New shucking plants are being constructed in Laguna Machona, Laguna Pajonal, and some other lagoons that will have more sanitary conditions. The government would like to improve the water quality in lagoons to meet the standards for harvesting shellfish set by the U.S. Food and Drug Administration so that oysters can be exported to the United States and other countries. One measure might be to transplant oysters from contaminated to certified bottoms. For the short term, oysters probably would have to be depurated before they would be sufficiently pure to meet export standards.

[14] Juana Almanda de Hernandez, Emiliano Zapata #12, Col. Progreso, Naranjas, Veracruz, Mex.

Future Prospects

The oyster industry of eastern Mexico appears to have a solid future. The Mexican people have become more conservation-minded and will try to preserve oyster resources and habitats (Galvan[1]). Abundances of oysters could be increased by spreading additional quantities of shells on beds. No surveys have

Figure 31.—Oyster meats in plastic bags being displayed for sale in a fish market in Coatzacoalcos, Veracruz.

Figure 32.—Eating an oyster cocktail in restaurant in Ciudad Del Carmen, Campeche.

been made as yet to determine whether deposits of fossil shells are present in the lagoons, but they probably exist because they are abundant in U.S. estuaries along the Gulf of Mexico from Louisiana to Florida (Gunter, 1951). If present, shells could be mined for spreading on the beds.

With the establishment of the North American Free Trade Agreement (NAFTA), the export of Mexican oysters to the United States would be encouraged more than in the past and production would expand. The impediment to export now is ensuring proper oyster sanitation.

Acknowledgments

We thank many people for providing information verbally. Their names are mentioned in the footnotes. Special thanks go to Jeronimo Ramos Saenz Pardo, Director General for Fisheries Management, SEMARNAP, Mexico City, for providing statistical data; and to Jose R. Perez, former shellfish dealer; and Juan Rogelio Galvan Utrera, Chief, Aquaculture Department, SEMARNAP, stationed in Villahermosa, Tabasco, for guided tours of oystering regions and providing much useful information. Henry Hildebrand, Professor Emeritus, University of Corpus Christi, Tex., critically reviewed the manuscript.

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The Status of Queen Conch, *Strombus gigas*, Research in the Caribbean

ALLAN W. STONER

History of Queen Conch Research

Today there are approximately 230 published scientific papers on queen conch, *Strombus gigas*. Publication on this species began in the 1960's and increased rapidly during the 1980's and 1990's (Fig. 1). The increase in publication after 1980 was associated with three particular areas of endeavor. First, many articles were published to document the rapid depletion of conch stocks throughout the Caribbean Sea. Second, substantial progress was made in understanding processes related to growth, mortality, and reproduction in queen conch. Third, because of the apparent and widespread decline in conch, several research laboratories, especially in Florida, Puerto Rico, Venezuela, and the Turks and Caicos Islands began experiments related to hatchery production of juvenile conch. The primary intent was to replenish wild stocks by releasing hatchery-reared animals. Today, hatchery production has been relatively well perfected, and the increase in numbers of scientific papers related specifically to culture has slowed. A thorough review of the history of conch mariculture was provided by Creswell (1994), and Davis (1994) summarized the details of larval culture technique.

In the last decade significant progress has been made in our understanding of the general biology, habitat requirements, distribution, and mortality processes that influence populations of juvenile conch. There has also been considerable effort to develop techniques related specifically to stock enhancement through release of hatchery-reared juveniles. Research on stock enhancement is still increasing at a steady rate, primarily in Florida and Mexico.

Little was known about the larval biology of queen conch prior to 1980. And, while culture technique was the primary focus of larval research in the 1980's, larval ecology and fisheries oceanography are the focus of those working with conch larvae in the 1990's. The first formal descriptions of the larvae of several *Strombus* species first appeared in 1993 (Davis et al., 1993), and we can now survey larvae quantitatively in the field. Publications on larval supply and transport, nutrition and length of life of larval stages, and larval settlement and recruitment are increasing rapidly. Another area of research that is new to the 1990's is related to the role of marine fishery reserves as a management tool for queen conch. All of these issues will be discussed below.

Objectives

An important scientific workshop on queen conch was held in Caracas, Venezuela, in July 1991. This workshop and the proceedings that emerged from it (Appeldoorn and Rodriguez, 1994) provided a good background on the status

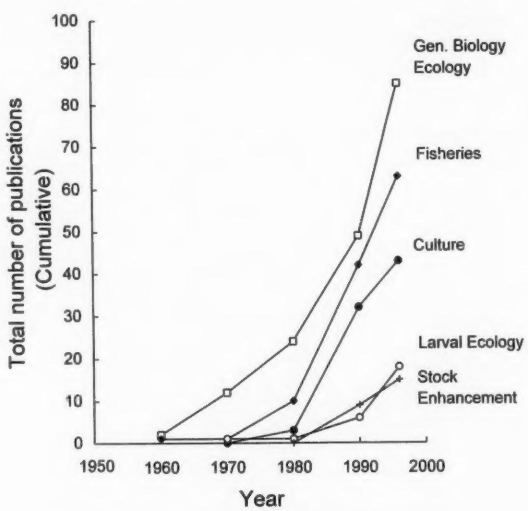

Figure 1.—Cumulative curves for the total numbers of published scientific articles on queen conch by five subdisciplines.

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of research on biology, fisheries, and mariculture of the queen conch. Because the general biology of the queen conch is already relatively well known, the purpose of this paper is to summarize some of the important advances made in the study of queen conch since the 1991 workshop. Emphasis has been placed on topics related to the ecology of queen conch that are most relevant to fisheries management and stock rehabilitation. In the following sections an attempt has been made to draw conclusions about habitat requirements for the species, mortality of juveniles as it relates to stock rehabilitation and enhancement, larval ecology and fisheries oceanography of the species, and the conservation of reproductive stocks.

Habitat Requirements and Nursery Grounds

While adult queen conch are now relatively uncommon in the shallowest regions of many Caribbean banks and island shelves, the most productive nurseries for the species tend to occur in shallow (<5–6 m deep) seagrass meadows. There are, however, certain exceptions, such as in Florida, where many juveniles are associated with shallow algal flats, and on certain deep banks such as Pedro Bank, south of Jamaica. Some juveniles are found in deeper shelf locations (>10 m depth), but these constitute a large proportion of the total juvenile source only in areas where shallow-water populations are very heavily impacted by fishing or habitat destruction.

Generally, larvae are transported by surface currents from spawning grounds onto shallow banks where the larvae settle and spend their first 2–3 years of life. Long-term studies near Lee Stocking Island in the Exuma Cays, Bahamas (Stoner et al., 1994, 1996a), and in the Florida Keys (Glazer[1]) have shown that aggregations of juveniles occur in the same locations year after year. Despite expansive distribution of seagrass beds in both the Bahamas and Florida, the conch nurseries occur in very specific locations within those meadows, and vast areas of seemingly appropriate seagrass beds are never occupied by conch. Near Lee Stocking Island, 90–95% of the vast seagrass meadow appears to be unsuitable for juvenile conch. Several factors appear to be important in providing environmental conditions appropriate for juveniles in the central Bahamas, and these principles appear to be relatively universal. Most nurseries are located in areas with an intermediate density of seagrass (usually 30–80 g dry wt/m^2) and in depths of 2–4 m. On the Great Bahama Bank, the largest, most productive nurseries for queen conch are located directly in the paths of strong tidal currents, and are flushed with clear oceanic water on every tide. Recent GIS (geographic information system) models of conch distribution (Jones, 1996) show that the locations of conch nurseries can be predicted with some degree of accuracy using a combination of seagrass biomass, water depth, and tidal circulation patterns.

The association of conch aggregations with particular locations may also be related to patterns of larval settlement. Recent laboratory experiments have shown that a wide variety of biological substrata affects settlement and metamorphosis in queen conch larvae; however, substrata such as seagrass detritus and sediment taken directly from nursery grounds induce settlement at a much higher frequency than the same materials taken from non-nursery locations (Davis and Stoner, 1994). Distributional pattern in early post-settlement conch also indicates that most settlement occurs in the immediate vicinity of the long-term nursery grounds (Stoner et al.[2]). Conch larvae are known to detect and settle in response to biological cues that are associated with subsequent high growth rates in the postlarvae (Stoner et al., 1996b), and juvenile conch are known to occupy areas that have exceptionally high algal productivity. It is also possible that conch larvae are concentrated in nursery areas before settlement. This will be discussed later in the section on Larval Ecology.

The uniqueness of queen conch nursery habitats has important implications for both fisheries management and stock enhancement of this seriously overfished resource. Despite the presence of very large seagrass meadows in certain conch-producing areas such as the Bahamas, Belize, Mexico, and Florida, only relatively small sectors of the meadows may actually have production potential for queen conch, either because they lack larval recruitment features or suitability as benthic habitat. Transplant experiments indicate that most seagrass beds, in fact, cannot support juvenile conch. The most productive nursery habitats appear to be determined by complex interactions of physical oceanographic features, seagrass and algal communities, and larval recruitment. These critical habitats need to be identified, understood, and protected to insure continued queen conch population stability.

Juvenile Mortality and Stock Enhancement

For at least 20 years it has been proposed that releases of hatchery-reared queen conch could be used to enhance or rehabilitate depleted populations (Berg, 1976). Mariculture technique for conch is relatively well perfected (Davis, 1994), and there are now hatcheries in the Caribbean region, most notably the Caicos Conch Farm[3] on the island of Providenciales, capable of producing millions of juveniles each year. However, high mortality has plagued conch planting efforts since the first releases were made in the early 1980's in Venezuela, the Bahamas, and Puerto Rico (Creswell, 1994).

In recent years many investigators have examined the various factors that influence mortality rates in juvenile conch. These factors include conch size, season, abundance of predators, density

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[1] Glazer, R. A. Florida Marine Research Institute, Department of Environmental Protection, South Florida Regional Laboratory, 2796 Overseas Highway, Suite 119, Marathon, FL 33050. Unpublished data are on file at the Florida Marine Research Institute.

[2] Stoner, A. W., M. Ray, and S. O'Connell. In Review. Settlement and recruitment of queen conch (*Strombus gigas*) in seagrass meadows: associations with habitat and micropredators.

[3] Mention of trade names or commercial firms does not imply endorsement by the National Marine Fisheries Service, NOAA.

of conch, structural complexity of the habitat (e.g. biomass of seagrass), and artifacts associated with hatchery rearing. Stoner and Glazer (In Press) recently combined the results of their respective long-term experiments in the Bahamas and Florida to provide a new synthesis of mortality data for queen conch. Although increasing survivorship of juvenile conch is ordinarily assumed to be directly related to conch size and age, with some degree of refuge in size occurring between 60 and 100 mm shell length (Jory and Iversen, 1983; Ray et al., 1994), Stoner and Glazer (In Press) learned that factors such as season, year, location, and conch density can have effects on survivorship as important as size. Recently, Ray et al. (In Press) learned that there is a large suite of very small predators that consume conch in the first weeks after settlement. In Bahamian nursery grounds, the most important of these, by virtue of their abundance, were xanthid crabs less than 5 mm in carapace width.

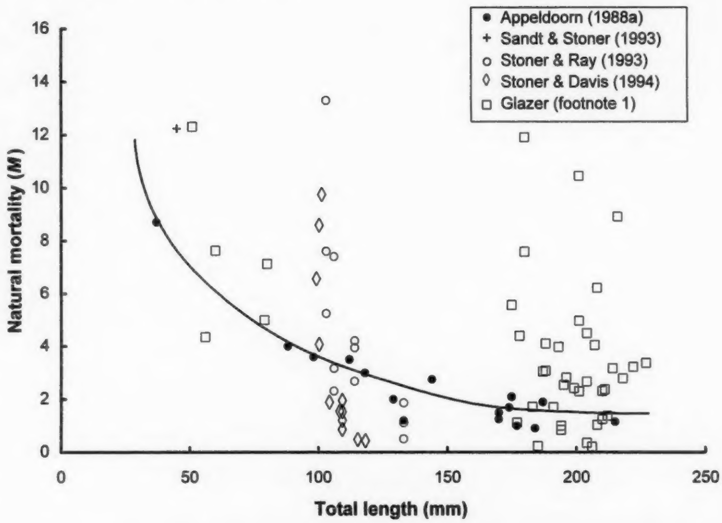

Figure 2.—Variation in instantaneous rates of natural mortality (*M*) for free-ranging juvenile queen conch. The curve shown was adapted from data provided by Appeldoorn (1988a) and is not intended to represent the points that are plotted for more recent investigations. Source: Stoner and Glazer (In Press).

Instantaneous rates of natural mortality (*M*), even in large juveniles, can vary by a factor of at least 10, from well below 1.0 to over 12.0 (Fig. 2). Because *M* is calculated as a logarithmic function, the probability of a conch surviving 1 year of life may vary by ten orders of magnitude, depending upon the time and location. It is clear that mortality rates of conch in natural populations can be extremely high. For example, instantaneous rates of natural mortality for small juveniles are commonly as high as 8.0–9.0. This means that an individual conch will have about a 1 in 10,000 chance of surviving over the next year.

Although hatchery production of juvenile conch is now relatively routine, hatchery-reared conch can have certain morphological, physiological, and behavioral deficiencies that increase their mortality in the field when compared with natural stocks. Stoner and Davis (1994) found that hatchery-reared queen conch grew more slowly than wild conch, had lower rates of burial, and they had shorter apical spines on the shells. All of these factors could negatively influence long-term survival of the hatchery-reared conch (Stoner, 1994). On the basis of their review, Stoner and Glazer (In Press) concluded that stock enhancement or rehabilitation that is dependent upon hatchery-reared conch has a relatively low probability of success because natural mortality rates in juvenile queen conch are high, growth rates are low, and hatchery-reared conch have numerous deficiencies. The problem is exacerbated by the continuing high cost of hatchery rearing.

It is possible that conch stocks in some locations are now so low that they cannot recover naturally. Larval recruitment data indicate that populations in U.S. waters may be in this category (see following section). In such cases, stock rehabilitation may depend on hatchery production, and the value of released conch will be determined by their survivorship to adulthood and their reproductive potential rather than their direct contribution to a fishery. Research in transgenerational enhancement may be particularly productive where populations have been severely reduced and fishing moratoria are in effect. Clearly, sound management of natural stocks is preferable to the daunting task of rehabilitating severely threatened stocks.

Larval Ecology and Fisheries Oceanography

While the culture of queen conch larvae was relatively well perfected in the late 1980's, the larvae of queen conch and closely related species were formally described only a few years ago (Davis et al., 1993). The first data on larval abundance in the field were also published in this decade (Stoner et al., 1992; Posada and Appeldoorn, 1994). Considerable progress has been made in the field of conch larval ecology and recruitment since the first descriptive studies.

We now know that conch larvae can be found in open water to depths as great as 100 m, but that most are found in the upper mixed layer of the ocean above the thermocline (Stoner and Davis, 1997b). In calm weather most are in the upper 5 m because of positive phototaxis (Barile et al., 1994). We also know that the larvae can develop in the field at rates higher than those typically observed in hatcheries using artificial

diets. Davis et al. (1996) reported metamorphosis of queen conch in periods as short as 14 days for larvae reared in field enclosures with natural assemblages of phytoplankton for food. Growth rates are strongly temperature dependent and sensitive to the amount and types of phytoplankton food available in the water column (Davis[4]). However, we have also learned that the larvae are capable of remaining in the water column for very long periods of time (perhaps 2 months) after reaching metamorphic competence (Noyes, 1996), and queen conch larvae have been collected in the mid-Atlantic Ocean near the Azores (Scheltema[5]).

The supply of conch larvae has a very important role in determining recruitment of conch to the nursery grounds and to the fishery. Recently, it has been shown that there is a direct positive relationship between the mean densities of late-stage larvae and the sizes of the juvenile populations in nursery grounds in both the Florida Keys and in the Exuma Cays, Bahamas (Stoner et al., 1996c). While the exact relationship was different in the two geographic regions, the fact that there is a close correlation between larval supply and juvenile population size within the systems indicates that the nursery grounds are not saturated with juveniles (i.e. the nurseries are below carrying capacity). Also, a positive correlation between year-class strength and larval supply has been observed near Lee Stocking Island in the Bahamas (Stoner[6]). These correlations, over both spatial and temporal scales, suggest that the populations of juvenile conch may be recruitment limited and that larval supply may determine the strength of recruitment on at least the local scale.

We have also observed that the locations of conch nurseries may be determined in part by local patterns of abundance in conch larvae. Near Lee Stocking Island, highest densities of late-stage queen conch larvae were found directly over locations known to support large aggregations of juvenile conch during surveys spanning seven years (Stoner and Davis, 1997a). Large, stable aggregations of juvenile queen conch were consistently supplied with high densities of larvae and were directly associated with tidal channels carrying larvae from offshore spawning grounds. In contrast, more ephemeral aggregations were characterized by low or inconsistent veliger densities (particularly late-stage larvae), and were generally outside primary tidal current pathways. Distribution of juvenile queen conch appears to be directly related to the horizontal supply of larvae.

Correlations between larval supply and juvenile population size over both spatial and temporal scales, along with data from transplant experiments, suggest that populations of queen conch are often recruitment limited, not habitat limited. Larval limitation implies that pre-settlement phenomena, such as growth and mortality during planktonic stages and larval transport, may be critical to population dynamics in queen conch. The positive relationship between larval supply and population size suggests that we need to understand transport processes and the mechanisms affecting larval supply to nursery grounds in order to understand recruitment process and year-class strength.

The relationship between oceanography and delivery of queen conch larvae to nursery grounds has been investigated in two systems: in Exuma Sound, Bahamas, and in the Florida Keys. Both studies show the dependence of populations upon upstream spawners.

In Exuma Sound, prevailing summer surface currents carry larvae away from the eastern rim of the Sound near Cat Island and onto the banks near the Exuma Cays on the western side of the Sound. Also, mesoscale gyres in Exuma Sound generally advance toward the northwest (Hickey[7]), transporting and concentrating larvae in the northern end of the system. The result is very large juvenile populations in the northern Exuma Cays and southern Eleuthera, and an historic record of high fisheries productivity in the northern Sound (Stoner, In Press). The full oceanographic interpretation of this mesoscale phenomenon is in progress.

The delivery of larvae to nursery grounds in the Florida Keys has also been analyzed (Stoner et al., 1997). In Florida, the queen conch population was reduced to such an extent that all conch fishing was banned in 1985. Between 1992 and 1994, estimates for the total number of adult queen conch in the entire Florida Keys island chain (250 km long) were between 5,800 and 9,200 individuals, and the Florida Department of Environmental Protection concluded that the population had shown no sign of recovery (Glazer and Berg, 1994; Glazer[8]). The fishing moratorium is still in effect.

Because there were so few queen conch in the local reproductive stock, Stoner et al. (1996c) postulated that the population in Florida is replenished with larvae produced outside the United States in the western Caribbean Sea (Mexico and Belize) and delivered to the nurseries on the Florida Current. To test this hypothesis, 35 collections of larvae were made in the Looe Key National Marine Sanctuary during the reproductive seasons of 1992 and 1994, concurrent with the deployment of a current meter array immediately offshore. In brief, most of the queen conch larvae collected at Looe Cay were late-stages that arrived in association with northward meanders of the Florida Current (Stoner et al., 1997). Late-stage conch larvae were never collected when the north wall of the Florida Current was offshore in the Florida Straits.

There are large spawning stocks in Belize and Mexico and recruitment of late-stage queen conch during periods of high eastward flow at Looe Key is consistent with the hypothesis that they have a source in the western Caribbean

[4] Davis, M. (In prep.). The effects of natural phytoplankton assemblages, temperature, and salinity on the length of larval life for a tropical invertebrate. Ph.D. dissert., Fla. Inst. Technol., Melbourne.

[5] Scheltema, R. S. 1995. Woods Hole Oceanographic Institution, Woods Hole, MA 02543. Personal commun.

[6] Stoner, A. W. Northeast Fisheries Science Center, National Marine Fisheries Service, NOAA, 74 Magruder Rd., Highlands, NJ 07732. Unpublished data are on file in the author's laboratory.

[7] Hickey, B. A. 1996. School of Oceanography, University of Washington, Seattle, WA 98195. Personal commun.

[8] Glazer, R. A., K. J. McCarthy, R. L. Jones, and L. Anderson. (In review). The use of underwater metal detectors to locate outplants of the mobile marine gastropod, *Strombus gigas* L.

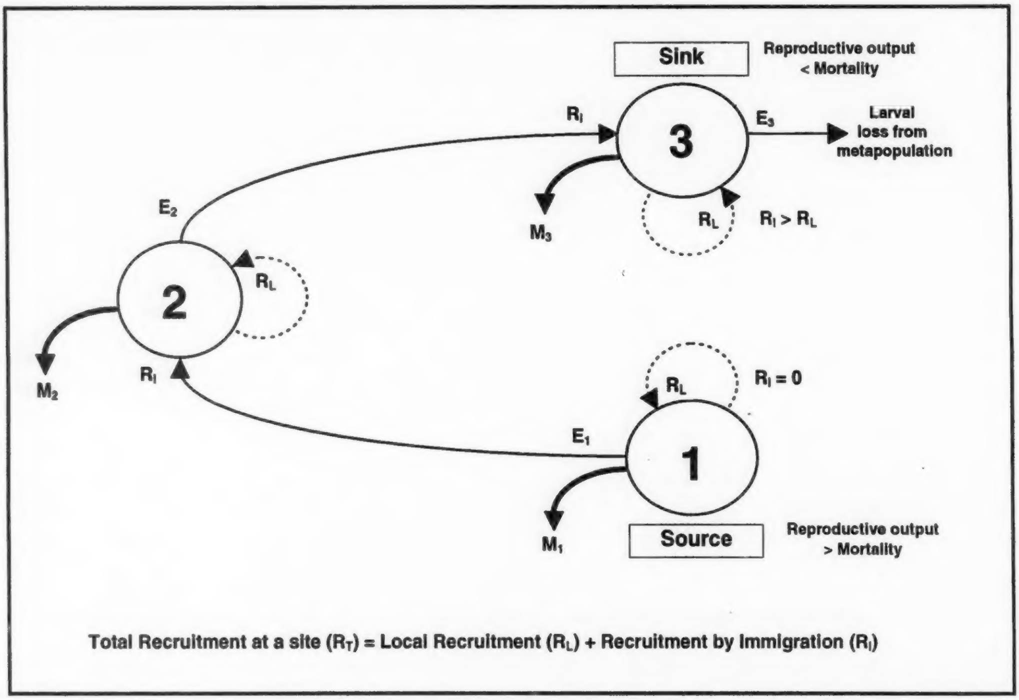

Figure 3.—Conceptual model of metapopulation dynamics. The model assumes a general circulation of water carrying larvae from Population 1 to 2 to 3. See text for definition of the model parameters.

Sea. The 3- to 4-week development period for queen conch larvae (Davis et al., 1993) in combination with average current velocities in the Loop Current and Florida Current system would permit transport from the Yucatan Strait to the Florida Keys. Concentrations of late-stage larvae are known to be high in the Florida Current 35 km south of the middle Keys (Stoner et al., 1996c), and arrival of conch larvae in association with easterly flow at Looe Key suggests that larvae of Caribbean origin are being delivered by the Florida Current. Although the genetic similarity between queen conch in the Caribbean Sea and Florida indicates significant gene flow (Mitton et al., 1989; Campton et al., 1992), the recent study by Stoner et al. (1997) provides the first oceanographic data indicating that a population of queen conch is dependent upon a source in an upstream nation.

It is possible that queen conch populations in Florida were historically self-sustaining, when adult populations were large. Today, however, recruitment appears to depend to a large extent on irregular and unpredictable northward meanders of the Florida Current. This would explain the lack of recovery in spawning stocks of queen conch since the fishing moratorium was established in 1985. Rehabilitation of this stock may now depend upon transplanting spawners or releasing hatchery-reared juveniles. However, stock enhancement through release of juveniles is difficult and expensive because of high potential mortality (described earlier) and has a history of low success (Stoner, 1994; Stoner and Glazer, In Press). Wise management and transgenerational enhancement of marine fishery resources will depend upon extensive knowledge of larval transport and recruitment processes.

Sources of larvae may be local if retention mechanisms are strong, or they may be distant, supplied by other nations. Although little is known about large-scale patterns of abundance and larval transport for any species in the Caribbean region, it is likely that most of the national populations are interdependent because of larval drift. This "open" nature of the populations requires that population dynamics be considered from a metapopulation perspective (Gilpin and Hanski, 1991). In the theoretical model presented in Figure 3 there are three subpopulations connected by larval transport. Population 1 is maintained by local recruitment (R_L) and has no recruitment by immigration from other sources (R_I). Reproductive (larval) output from Population 1 is greater than local mortality (M), and some of that output is exported to downstream populations (E). In metapop-

ulation terminology, this population is a "source." Populations 2 and 3 are downstream from Population 1 and receive larvae both from local spawners (R_L) and from upstream sources (R_I). By definition, Population 3 is a "sink" because reproductive output is less than local mortality, and most larval production is lost from the system. Population 2 is a "source" for Population 3, but may also be a "sink" depending upon the relationship between R_L and M_2.

Practical examples of "sources" and "sinks" can be hypothesized in the Caribbean region. The Windward Islands are probably "source" locations, analogous to Population 1 in the model because of the general east-to-west circulation of surface waters through the Caribbean Sea. In the eastern Caribbean, populations of queen conch and other species with pelagic larvae must be maintained by local recirculation patterns. Island-scale self-recruitment mechanisms have been discussed in general by Farmer and Berg (1989), and more specifically for Bermuda (Schultz and Cowan, 1994) and Barbados (Cowan and Castro, 1994), which are probably dependent upon local retention of fish larvae. Florida conch populations may receive larvae from local spawning populations; however, the populations are so low today that Florida is probably a "sink" with heavy dependence upon upstream sources of larvae, as described earlier. Important conch-producing locations such as Belize and Pedro Bank are probably more analogous to Population 2 in the model, with characteristics of both "sources" and "sinks."

Position within the metapopulation structure can have important management consequences. For example, a source population will be highly vulnerable to recruitment overfishing, and emphasis must be placed on maintaining an effective and sustainable reproductive stock quality. Downstream populations are also dependent upon larvae from these source populations. A sink-type population is more susceptible to management practices occurring in the upstream source locations than to those effected by local management practice. Recovery of depleted stocks requires an adequate source of larvae which may or may not be local. For these reasons, a strong effort should be made to identify the sources of larval recruitment for target populations, and stock management should be based upon the associated metapopulation structure.

Conserving Reproductive Stocks

It is obvious from the previous discussion that it is important to maintain a regular, high-density supply of larvae to queen conch nurseries by preserving reproductive populations of adequate size. Reproductive stocks and reproduction are protected by a variety of management techniques that have been discussed by others. In this section, results from two new investigations bearing on the role of conch reproduction are described.

In the summer 1995, the Caribbean Marine Research Center conducted surveys of adult conch in the Exuma Cays, Bahamas, to test for hypothesized relationships between adult conch density and reproductive behavior (Stoner[9]). Protection of conch in the Exuma Cays Land and Sea Park presented the unusual opportunity to examine a wide range of spawner densities, from a few conch per hectare to approximately 650 per hectare. The surveys showed that 10–30% of the conch were usually laying eggs at any one time and place during the summer reproductive season, but the data suggest a decline at densities less than about 50 adult conch/ha. Similar declines were observed in the relative abundance of mating pairs of conch at about 50 conch/ha. Given that reproduction in queen conch requires internal fertilization of eggs, it is possible that some threshold of adult density is required for males and females to detect one another and mate. The exact density at which reproduction is depressed probably varies with location, the overall size and scale of the population, and natural aggregation of adults during the summer spawning season. However, it is clear that a minimum spawner density is important for successful reproduction in queen conch (Appeldoorn, 1988b). While quantitative surveys have been made in relatively few locations in the greater Caribbean region, 50 adult conch/ha is significantly higher than the densities reported in many locations, including Bermuda, Florida, Puerto Rico, the U.S. Virgin Islands, and Venezuela, in recent years (Stoner and Ray, 1996).

There are at least two ways to protect high densities of adult queen conch: depth refugia and marine reserves.

Depth Refugia

Queen conch are herbivorous, consuming micro- and macroalgae throughout their lives as benthic juveniles and adults. Therefore, conch are found in well-lighted regions of the marine environment from the shallowest subtidal zone down to depths of about 35–40 m in clear Caribbean water. There have been a few reports of queen conch observed in depths to 60 m but these individuals are very rare.

Detailed depth distributions for adult conch have been reported for Puerto Rico, the U.S. Virgin Islands, and the central Bahamas. In Puerto Rico, maximum adult density occurred at 20–25 m, but the densities at this depth were very low (0.05 conch/ha) (Torres Rosado, 1987). This deep distribution of adults was attributed to fishing pressure. In less heavily fished waters of the U.S. Virgin Islands, maximum adult density was (17.1 adults/ha) in a depth range of 18–24 m (Friedlander et al., 1994). Near Lee Stocking Island in the Bahamas, maximum density (88 adults/ha) was observed in 15–20 m depth, and densities were approximately 18 adults/ha in 20–25 m depth (Stoner and Schwarte, 1994), similar to values in the Virgin Islands. Although direct comparisons must be made with caution, it is clear that where fishing is open to scuba diving, as in Puerto Rico, maximum abundance of adult conch is driven to great depth, and numbers at all depths are generally very low. This is in sharp contrast with relatively natural populations of adults in the Exuma Park where the highest abundance of adults (270 adults/ha) occurs in depths

[9] Stoner, A. W. Northeast Fisheries Science Center, National Marine Fisheries Service, NOAA, 74 Magruder Rd., Highlands, NJ 07732. Unpublished data are on file in the author's laboratory.

of just 10–15 m (Stoner and Ray, 1996; Table 1). In the Bahamas, where fishing is limited to free diving, adult conch are relatively uncommon in depths shallower than 10 m but densities increase rapidly with depth beyond the reach of the average free-diving conch fisherman.

Very few conch live deeper than 30 m, and virtually all are accessible to scuba divers. One potential form of management for a healthy reproductive population, therefore, is to limit fishing to free diving. However, because the vast majority of queen conch spend their first 2–3 years in shallow water, young adults and adults that do not migrate to deep water are all accessible to free divers, it is possible that intense fishing for conch in shallow water could ultimately reduce deep-water stocks. This apparent dilemma was discussed earlier by Stoner and Ray (1996).

Marine Reserves

Closed areas represent another mechanism for maintaining high densities of adult conch. The Exuma Cays Land and Sea Park is a marine fishery reserve established in 1958 and administered by the Bahamas National Trust in the central Bahamas. The Park is large, spanning a section of the northern Exuma Cays 40 km long and 8 km wide. No fishing of any kind has been permitted since approximately 1984. Stoner and Ray (1996) conducted extensive, depth-stratified surveys in the Park and near Lee Stocking Island to compare the abundance of adults, juveniles, and larvae of queen conch in a marine fishery reserve and in a nearby fished area of the Exuma Cays. Large differences in densities of adult conch between the reserve and the fished area are obvious (Table 1). Differences in densities of adult conch were significant in all depth zones down to 30 m, except in the very shallow shelf region (0–2.5 m depth), and, as would be expected, this marine reserve conserves spawners. One of the most notable differences between the two sites was that densities were 30 times higher in the shallow bank environment of the reserve than in comparable habitat in the fished area. The bank represents a very large habitat in the Exuma Cays and the contribution of the bank to the adult population was enormous. Additionally, conch density on the bank in the reserve was sufficiently high to promote reproduction in that habitat.

Table 1.—Density of adult queen conch in the Exuma Cays Land and Sea Park near the island of Waderick Wells and in the fished area near Lee Stocking Island, Exuma Cays. Values for adult density are mean ± SE for each depth interval. The bank habitat was represented by a 5 km wide band of the shallow (0–5 m deep) Great Bahama Bank immediately to the west of the island chain. The shelf habitats were to the east of the islands where depths increased gradually out to the shelf-break which began at about 30 m depth. Stoner and Ray (1996) provide full details.

Habitat/ depth (m)	Marine reserve	Fished area
Bank	53.6	1.7
Shelf		
0.0–2.5	0 ± 0	0 ± 0
2.5–5	34 ± 22	2.2 ± 1.7
5–10	49 ± 18	7.2 ± 4.1
10–15	270 ± 85	60 ± 47
15–20	104 ± 58	88 ± 32
20–25	148 ± 72	18 ± 9
25–30	122 ± 70	0 ± 0

Because of the high abundance of spawners, there were about 10 times more newly-hatched larvae in the unfished area than the fished area (Stoner and Ray, 1996). An alongshore drift of about 1.5–3 km per day and a mesoscale gyre in the northern Exuma Sound then carry larvae produced in the fishery reserve to nurseries in the northern Exuma Cays and southern Eleuthera. Reports from fishermen and from the Department of Fisheries indicate that the numbers of juvenile conch have increased in these areas over the last 10 years, the time period during which fishing has been closed in the Exuma Park. Although the observations must be considered anecdotal, the high production of larvae in the fishery reserve undoubtedly contributes to fished populations in downstream areas.

The apparent success of the Exuma Cays Land and Sea Park in protecting spawning stocks of queen conch and in producing high numbers of larvae for export to surrounding areas is due, in part, to its large size (about 320 km^2). Reserves must be large enough such that most of the reproductive stock cannot migrate out of protected areas to be captured. We also need to consider larval transport and physical oceanography in the design of fishery reserves. They must receive a regular supply of larvae from some spawning population, and they must be established in locations that will contribute to the downstream fishery. Reserve design should be developed in the context of metapopulation dynamics discussed earlier.

Conclusions

Research on queen conch continues to accelerate because of stock depletion throughout the Caribbean region and interest in stock rehabilitation. Recent advances are related to habitat requirements and survivorship of juveniles, larval ecology, fisheries oceanography, and certain management practices.

The majority of juvenile conch occur in a few unique habitats. These nursery grounds are defined by a suite of abiotic and biotic characteristics, including water circulation, patterns of larval accumulation and settlement, production of foods, and differential mortality. These nursery habitats must be identified and protected from destruction.

Stock enhancement through release of hatchery-reared conch has not been successful because of low growth rates and high natural mortality in juvenile conch. Release techniques are improving in parallel with good information on the variables that affect the highly variable mortality rates, but seed costs remain high, and hatchery-reared conch bear certain physiological, morphological, and behavioral deficiencies.

Recruitment to the juvenile class appears to be dependent upon the numbers of larvae supplied to the nursery grounds, on both spatial and temporal (interannual) scales. Locations with large populations of juveniles and adults receive regular deliveries of conch larvae in high density.

Populations of queen conch within the Caribbean region are probably interdependent because of larval drift on ocean currents for periods of time between two weeks and two months. The extent of interdependence among populations and among nations is poorly known; however, management of the conch resource must be considered within a metapopulation context. The significance of larval drift to fisheries management is an area of research that warrants much new research.

Successful reproduction of queen conch is related to adult density, particularly at low density. Although the lower threshold for normal reproductive behavior is unknown, density-dependent reproductive behavior has important management implications and should be explored.

Populations of queen conch significant to the fishery all occur within the depth range of scuba divers, consequently all conch are vulnerable to this form of fishing pressure. Given that relatively healthy populations of conch are now limited primarily to nations where scuba is prohibited in the collection of conch, this form of management appears to have a positive effect.

Marine reserves can protect adult populations of queen conch and supply larvae to fished areas downstream from the reserves. Fishery reserves protect the integrity of spawner density for high reproductive efficiency and larval production. The size of reserves needs to be large enough to prevent the adult stocks from emigrating readily over the reserve boundaries, and the location should be chosen with the objective of producing larvae that will be carried to suitable downstream nursery areas.

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Estimation of Standardized Effort in the Heterogeneous Gulf of Mexico Shrimp Fleet

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ABSTRACT—In this paper we estimate nominal and standardized shrimping effort in the Gulf of Mexico for the years 1965 through 1993. We accomplish this by first developing a standardization method (model) and then an expansion method (model). The expansion model estimates nominal days fished for noninterview landings data. The standardization model converts nominal days fished to standard days fished. We then characterize the historical trends of the penaeid shrimp fishery by vessel configuration, relative fishing power, and nominal and standardized effort. Wherever possible, we provide comparison with previous estimates by the National Marine Fisheries Service, NOAA.

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Introduction

The Gulf of Mexico penaeid shrimp fishery is one of the most valuable single U.S. fisheries and represents one of the greatest sources of fishing pressure within the Gulf. Because the otter trawl used in this fishery is nonselective, it has a direct impact on important finfish utilized in other directed commercial and recreational fisheries. There is an increasing emphasis on reducing the extent of this bycatch in order to rebuild certain fish stocks (particularly the red snapper, *Lutjanus campechanus*). Although Nichols et al.[1] attempted to estimate the impact, accurate measurement of bycatch has not been possible because only estimates of nominal fishing effort (actual hours of fishing per trip; not standardized effort[2]) have been available from the National Marine Fisheries Service (NMFS).

The effort data set[3] available from NMFS is based both upon landings as reported to NMFS port agents by dockside dealers and agent interviews with shrimpers who are in port. Several concerns have arisen about this effort data set. First is the possibility that the number of interviews may not represent the true proportion of landings and effort by craft type. Secondly, NMFS has had to estimate CPUE (catch per unit of effort) for certain areas and times due to lack of interviews with shrimpers in those areas and times (Nance, 1992). Finally, several characteristics of fishing power (vessel size, number of nets per craft, number of vessels operating) have varied during the period represented by the historical data set.

[1] Nichols, S., A. Shah, G. J. Pellegrin, Jr., and K. Mullin. 1990. Update estimates of shrimp fleet bycatch in the offshore shrimp fishery of the U.S. Gulf of Mexico 1972–1989. Rep. to Gulf Mex. Fish. Manage. Counc., by NMFS Mississippi Laboratories, Pascagoula MS 39568-1207.

[2] A unit of nominal effort is defined as net(s) being pulled in the water for a period of 24 h (known in the industry as a day fished). Standardized effort is defined as adjusted nominal effort based on the relative fishing power (RFP) of each vessel in the Gulf of Mexico shrimp fleet relative to a standard vessel.

[3] The NMFS uses catch per unit of effort (CPUE) generated from landings data with associated days fished obtained from interviewing fishermen to calculate effort for noninterviewed landings data (Nance, 1992).

Recently, interest in accurate estimates of current bycatch and its mandated reduction, was coupled with concern (expressed both by shrimp fishermen and the Gulf of Mexico Fisheries Management Council (GMFMC)) about potential bias inherent in the effort data set as produced by NMFS. Therefore, a "Shrimp Fishing Effort Estimation Workshop" was held June 1992 at the Galveston Laboratory of the NMFS Southeast Fisheries Science Center. The goals of the workshop were to: "1) use the shrimp total landing data (pounds by area and month) and trip interview data (pounds per fishing hour by area and trip) to develop methods to estimate nominal effort (actual days fished) in the shrimp fishery of the U.S. Gulf of Mexico and 2) recommend which method should be used by the NMFS to estimate nominal effort each year. Since the effort values are used to estimate finfish bycatch in the shrimp fishery, there is a critical need to develop a statistically valid effort estimation method" (Nance, personal commun., 1 June 1992).

The NMFS expands interviewed effort data into nominal days fished using a simple average CPUE for boats and vessels in each cell, where a cell is defined by a combination of month, area, and depth (Nance, 1992). Since the simple average CPUE of all boats and vessels does not take into account any nonproportionality in sampling of boats and vessels, the resulting estimates could be biased. This bias may be in any direction depending on the nonproportionality in sampling of boats and vessels in each of the cells (see box on next page). To realize the extent of nonproportional sampling over the years, Figure 1a shows the percent of

Example of Simple Average Resulting in Biased Total Days Fished

Example 1 represents a hypothetical case where proportional sampling was accomplished. In this example total landings is 100,000 pounds each by vessels and boats, giving total landings of 200,000 pounds. The total amount of interviewed pounds for vessel and boats is 10,000 each, giving total interviewed landings of 20,000 pounds. This means that 10% of total pounds were interviewed for both vessels and boats, i.e. proportional sampling. Interviewed days fished is 40 for vessels and 20 for boats. The CPUE for vessels is 250 and the CPUE for boats is 500. The simple average CPUE for both vessels and boats is 333 (20,000/60 = 333). Estimated days fished for vessels would be 400 (100,000/250 = 400) and the estimated days fished for boats would be 200 (100,000/500 = 200). Adding expanded days fished for vessels and boats gives 600 estimated days fished (400 + 200 = 600). Using the CPUE for vessels and boats we get the same results (200,000/333 = 600). Thus, when interviews pounds are proportional to total pounds for vessels and boats, then using the simple average leads to a correct estimate of total days fished.

It is interesting to note that if only vessels had been sampled, the estimated days fished would have been 800 (200,000/250 = 800) and if only boats had been sampled the estimated days fished would have been 400 (200,000/500 = 400). The reason this calculation is added is that there are many month, statistical zone, and depth combinations in the Gulf of Mexico where both vessels and boats fish but only vessels or boats are interviewed, but not both. A prime example would be Texas where only large vessels are targeted for interview.

Example 2 is almost the same as example 1 except boats now have 20,000 interviewed pounds and 40 interviewed days fished. Notice that the CPUE for vessels and boats is the same as in example 1 and the weighted average estimated total days fished is unchanged at 600. However, the simple average CPUE has changed from 333 in example 1 to 375 (30,000/80 = 375) in example 2. Boats now are weighted heavier than vessels in example 2. As a result of this nonproportional sampling the estimated days fished is 533 (200,000/375 = 533) using the simple average CPUE of 375. Estimated days fished are underestimated by 67 days fished (600–533 = 67).

Examples 3 and 4 are actual data from the Gulf of Mexico at a given month, statistical zone, and depth. In example 3 estimated days fished are under estimated by 51% using the simple average. In example 4 estimated days fished are over estimated by 20%.

Example 1.—Hypothetical data showing proportional sampling results in unbiased estimate of days fished.

Item	Total pounds	Pounds (interviewed)	Days fished (interviewed)	CPUE	Days fished (estimated)
Vessels	100,000	10,000	40.0	250	400
Boats	100,000	10,000	20.0	500	200
Total vessels & boats	200,000	20,000	60.0	333	600
Simple average					600
Weighted average					600
Only vessels					800
Only boats					400

Example 2.—Hypothetical data showing nonproportional sampling results in biased estimate of days fished.

Item	Pounds	Pounds (interviewed)	Days fished (inteviewed)	CPUE	Days fished (estimated)
Vessels	100,000	10,000	40.0	250	400
Boats	100,000	20,000	40.0	500	200
Total vessels & boats	200,000	30,000	80.0	375	533
Simple average					533
Weighted average					600
Only vessels					800
Only boats					400

Example 3.—Nonproportional sampling results in biased estimate of days fished in the Gulf of Mexico for the month of August, statistical zone 12 and inshore.

Item	Pounds	Pounds (interviewed)	Days fished (interviewed)	CPUE	Days fished (estimated)
Vessels	241,812	26,997	37.9	712	339
Boats	225,288	221,768	68.0	3,261	69
Total vessels & boats	467,100	248,765	105.9	2,349	199
Simple average					199
Weighted average					409
Only vessels					656
Only boats					143

Example 4.—Nonproportional sampling results in biased estimate of days fished in the Gulf of Mexico for the month of December, statistical zone 17 and 0–5 fathoms.

Item	Pounds	Pounds (interviewed)	Days fished (inteviewed)	CPUE	Days fished (estimated)
Vessels	119,289	45,644	66.5	686	174
Boats	22,799	22,799	79.7	286	80
Total vessels & boats	142,088	68,443	146.2	468	304
Simple average					304
Weighted average					253
Only vessels					207
Only boats					497

Figure 1a.—Percent of inshore landings by vessels and boats compared to percent of inshore interviewed landings by vessels and boats (data for 1976–80 is unavailable).

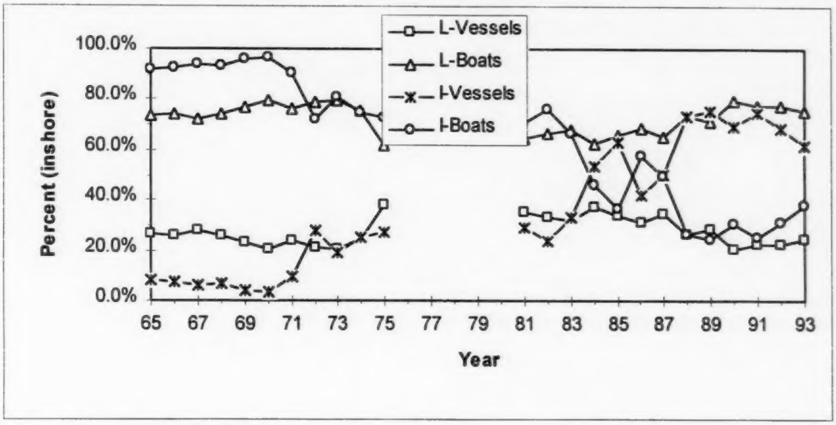
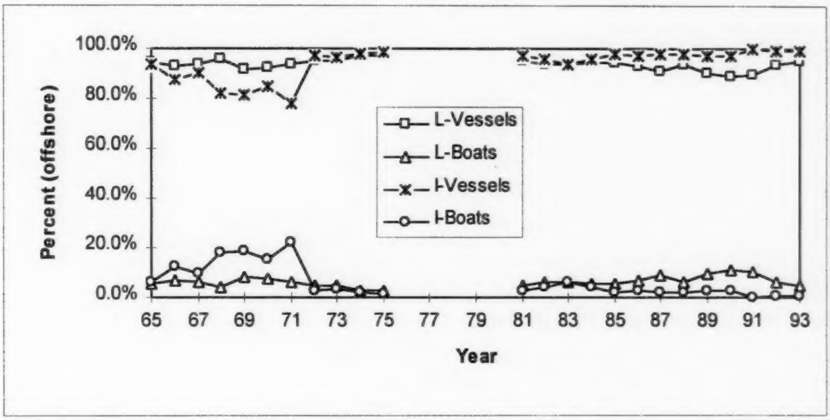


Figure 1b.—Percent of offshore landings by vessels and boats compared to percent of offshore interviewed landings by vessels and boats (data for 1976–80 is unavailable).



landings by vessels and by boats in the inshore shrimp fishery. The lines labeled L-Vessels and L-Boats show the percent of total landings in the inshore by vessels and boats, respectively. The lines labeled I-Vessels and I-Boats show the percent of interviewed landings in the inshore by vessels and boats, respectively. In 1965, boat total landings were about 72% and vessel landings were about 28%. Boat interviewed landings, however, were about 92% and vessel landings were about 8%. Sampling of vessels and boats was nonproportional (nonrepresentative) since there were too many boats being interviewed in the inshore shrimp fishery relative to vessels in 1965. This pattern continues until 1972. Sampling of vessels and boats was much more representative from 1972 to 1983 (ignoring 1976–80). In 1984, obviously, vessels are more frequently targeted for interview than boats even though this is a predominately a boat-type fishery. The interviewed data have become highly nonrepresentative in these latter years causing higher bias in the estimated total days fished through simple average CPUE in the inshore shrimp fishery. Figure 1b shows the trend on the offshore shrimp fishery. Under proportional sampling, the lines for L-Vessels and I-Vessels should coincide and the lines for L-Boats and I-Boats should coincide. The degree of noncoincidence of these lines reflects the nonproportionality in the Figures 1a and 1b. Figure 2a, which shows the percent of inshore landings by boats and vessels being interviewed, illustrates this problem more clearly. While the 30–60% of boat landings were interviewed in early years, virtually no interviews have occurred since 1989. Interviewed vessels landings have remained around 10% until 1989 when these interviews also began to decline.

In the offshore shrimp fishery, which is predominantly a vessel fishery, the same general pattern occurs for both vessels and boats. Higher proportions of boats were sampled in the earlier years and higher proportions of vessels were sampled in the latter years (Figure 2b). As with the inshore shrimp fishery the percent of boat landings interviewed from the offshore is very small whereas the same for the vessels has varied around 20% for the entire time period. Ideally, under the proportional sampling, the two lines in Figures 2a and 2b should coincide. The degree of noncoincidence reflects the degree of nonproportionality.

Figure 2a.—Percent of inshore landings interviewed by vessels and boats (data for 1976–80 is unavailable).

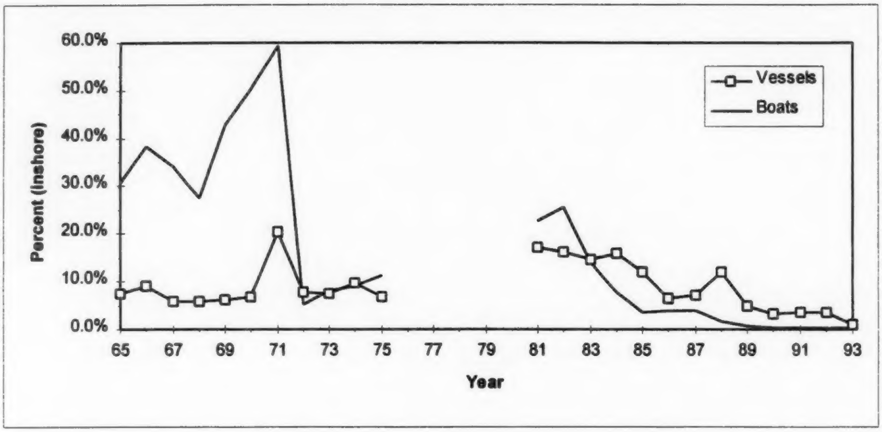
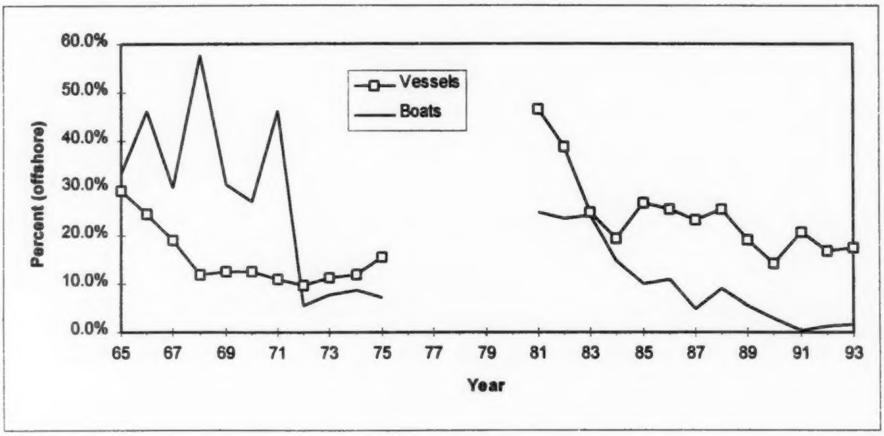


Figure 2b.—Percent of offshore landings interviewed by vessels and boats (data for 1976–80 is unavailable).



This paper presents the development of a method to standardize effort. It also presents an alternative to the NMFS method to estimate nominal effort. These methods are expected to produce better estimates of nominal and standardize effort suitable for use in research both by biologists (Nichols et al.[1]) and economists (Grant and Griffin, 1979; Griffin et al., 1993a, b; Hendrickson and Griffin, 1993) on issues such as bycatch. We also characterize the historical trends of vessel configuration in the shrimp fishery, relative fishing power, and nominal and standardized effort.

Methods

The Modeling Approach

Shrimp catch for a given vessel at a given location × time (cell) is a function of vessel effort and abundance of shrimp, i.e.

$$C_{ijt} = E_i\left(\alpha A_{jt}^{\beta}\varepsilon_{ijt}\right), \qquad (1)$$

where, C_{ijt} is catch by vessel i in location j and time t, E_i is effort level (power or ability) of vessel type i, A_{jt} is abundance level in location j and time t, ε_{ijt} is the random error term, and α and β are the model parameters.

Equation (1) is log-linear which is expected to provide a better fit than a straight linear model (Gulland, 1956; Beverton and Holt, 1957; Robson, 1966). The standard assumptions associated with such models (Draper and Smith, 1981; Kleinbaum et al., 1988; Sen and Srivastava, 1990; Hamilton, 1992), were checked statistically for validity. Only C_{ijt} is directly observable and available, while variables E_i and A_{jt} can be modeled as a function of other variables as discussed below.

Effort (Power or Ability) Model

Vessel effort produced during a unit of fishing time is a function of its physical characteristics. The skills of the captain and the crew, as well as the onboard technology (electronic equipment, etc.), are important variables, but often are difficult to measure and incorporate in the model. The lack of data prevented inclusion of these variables in the model. The log-linear effort model for vessel i can be written as

$$E_i = \alpha_E V_{i1}^{\beta_{E1}} V_{i2}^{\beta_{E2}} \ldots V_{in}^{\beta_{En}} \varepsilon_{Ei} \qquad (2)$$

where, V_{ik} is the kth characteristics ($k = 1, 2, \ldots, n$) of vessel i, (e.g. horsepower,

length, gear type, etc.), α_E, $\beta_{E1}, \beta_{E2}, \ldots, \beta_{En}$, are the model parameters, and ε_{Ei}, is the random error term. This type of function allows for diminishing returns. That is, as inputs (vessel length, quantity of fishing gear, etc.) increase for a given level of stock abundance, output (catch of shrimp) will increase but at a decreasing rate.

Abundance Model

Abundance, defined as the amount of shrimp available for harvest, is dependent upon time and location[4]. When necessary, some of these factors were incorporated into the model using dummy variables. The log-linear abundance model can be written as

$$A_{jt} = \alpha_A X_{jt1}^{\beta_{A1}} X_{jt2}^{\beta_{A2}} \ldots X_{jtm}^{\beta_{Am}} \varepsilon_{Ajt} \qquad (3)$$

where, X_{jtl} is the lth abundance factor, $l = 1,2, \ldots, m$, in time period t in location j, α_A, $\beta_{A1}, \beta_{A2}, \ldots, \beta_{Am}$, are the model parameters, and ε_{Ajt}, is the random error term.

Catch Model

Using equations (2) and (3), the catch model can now be expressed as

$$\begin{aligned} C_{ijt} &= \left(\alpha_E \prod_{k=1}^{n} V_{ik}^{\beta_{Ek}} \varepsilon_{Ei}\right)\alpha \left(\alpha_A \prod_{l=1}^{m} X_{jtl}^{\beta_{Al}} \varepsilon_{Ajt}\right)^{\beta} \varepsilon_{ijt} \\ &= \left[\alpha_E \alpha \alpha_A^{\beta} \prod_{k=1}^{n} V_{ik}^{\beta_{Ek}} \prod_{l=1}^{m} \left(X_{jtl}^{\beta_{Al}}\right)^{\beta} \left(\varepsilon_{Ei} \varepsilon_{Ajt}^{\beta} \varepsilon_{ijt}\right)\right] \\ &= \lambda \prod_{k=1}^{n} V_{ik}^{\lambda_k} \prod_{l=1}^{m} X_{jtl}^{\delta_l} \xi_{ijt} \qquad (4) \end{aligned}$$

[4] Shrimp is an annual crop and very dependent on environmental parameters such as water temperature, salinity, etc., in any given time period and location. However, these environmental parameters were not used in the model since they were not available throughout the Gulf.

where, $\lambda = \alpha_E \alpha \alpha^{\beta}_A$; $\lambda_k = \beta_{Ek}$ ($k = 1, 2, \ldots n$); $\delta_l = \beta_{Al}\beta$ ($l = 1, 2, \ldots, m$); and $\xi_{ijt} = \varepsilon_{Ei}\varepsilon^{\beta}_{Ajt}\varepsilon_{ijt}$.

Using the Beverton and Holt (1957) definition of relative fishing power (*RFP*), the *RFP* index of vessel i can be calculated simply by taking the ratios of the estimated C_{ijt} to C_{sjt}, where the subscript s refers to the standard vessel chosen subjectively. For any given time-location stratum and for a constant level of nominal days fished, the estimated *RFP* index of vessel i is defined as,

$$RFP_i = \frac{\prod_{k=1}^{n} V_{ik}^{bk}}{\prod_{k=1}^{n} V_{sk}^{bk}} = \prod_{k=1}^{n} \left(\frac{V_{ik}}{V_{sk}}\right)^{bk} \qquad (5)$$

The model in (5) proposed here is a more general model than the ones used by Beverton and Holt (1957) and Robson (1966) by allowing the inclusion of dummy variables.

Now, the estimated standardized total effort (*TE*) of all vessels (*V*) can be computed as

$$TE = \sum_{i=1}^{V} (RFP_i)(DF_i), \qquad (6)$$

where DF_i is the nominal days fished by vessel i, and V is the total number of vessels. It should be noted that DF_i is both estimated and observed data. Only noninterview landing data has estimated days fished, whereas, interview landings data has observed days fished.

Results

The Standardization Model

The General Linear Model (GLM) procedure, utilizing SAS software, was used to derive the standardization of effort. This is the most common procedure used in the situations where the cells have missing values and are unbalanced. Moreover, it has been shown to be robust to the departures from some of the standard GLM assumptions. The log transformation was used in an attempt to normalize the data, to homogenize the variances, and to achieve additivity in the model. We modeled the natural log (ln) of catch per trip (*CPT*)[5] as function of several abundance and vessel characteristics variables:

$$\ln(CPT) = \text{g[month, area, depth, year, construction, ln(gross tons), ln(length), ln(year built), ln(horsepower), ln(no. crew), ln(footrope), ln(no. nets), ln(days fished/trip)]} + \varepsilon. \qquad (7)$$

The only variables contributing significantly to the models were month, area, depth, year, ln(length), ln(footrope), and ln(days fished/trip). The coefficient of determination (R-square) for this reduced model was 0.7935. The fitted model (Table 1a) as well as all the terms in the fitted model (Table 1b) are highly significant (with each $P< 0.0001$). Table 2 gives the regression coefficients and corresponding P values for the model. The *RFP* index estimate can now be computed as follow:

$$\begin{aligned} RFP\ index &= \frac{(FRL_{CV})^{0.34}(VL_{CV})^{0.31}}{(FRL_{SV})^{0.34}(VL_{SV})^{0.31}} \\ &= \left(\frac{FRL_{CV}}{FRL_{SV}}\right)^{0.34} \left(\frac{VL_{CV}}{VL_{SV}}\right)^{0.31} \qquad (8) \end{aligned}$$

[5] Some may prefer to use ln(*CPUE*) as the independent variable. This would be algebraically identical to our model since ln(*CPUE*) = ln(*CPT*/*DFPT*) = ln(*CPT*) − ln(*DFPT*) where *DFPT* is days fished/trip.

Table 1a.—ANOVA table for the standardization model for ln(*CPT*)[1].

Source	DF	Sum of squares	Mean square	F value	Prob > F
Model	55	455,828	8,288	20,594	0.0001
Error	294,841	118,657	0.4024		
Corrected	294,896	574,484			

[1] *CPT* is catch per trip.

Table 1b.–Breakdown of model degrees of freedom from Table 1a.

Source	DF	F Value	Prob > F
Month	11	3,763	0.0001
Year	27	1,034	0.0001
Area	9	579	0.0001
Depth	5	343	0.0001
Ln(DFPT)	1	100,000	0.0001
Ln(Footrope)	1	2,993	0.0001
Ln(Length)	1	1,091	0.0001

Table 2.—Estimates of standardization model parameters and p-values.

Variable	Estimate	Prob > ITI	Variable	Estimate	Prob >ITI
Intercept	2.7214	0.0001	1981	0.3856	0.0001
January	–0.1116	0.0001	1982	0.0746	0.0001
February	–0.3244	0.0001	1983	–0.0184	0.0667
March	–0.3793	0.0001	1984	0.1848	0.0001
April	–0.4081	0.0001	1985	0.3328	0.0001
May	–0.1872	0.0001	1986	0.2428	0.0001
June	0.2324	0.0001	1987	0.0050	0.6139
July	0.4172	0.0001	1988	–0.1059	0.0001
August	0.2917	0.0001	1989	0.0132	0.2287
September	0.1447	0.0001	1990	0.0183	0.109
October	0.1246	0.0001	1991	0.1433	0.0001
November	0.1098	0.0001	Area 1–3	0.6861	0.0001
1965	0.6380	0.0001	Area 4–6	0.5443	0.0001
1966	0.6384	0.0001	Area 7–9	0.6066	0.0001
1967	0.6807	0.0001	Area 10–12	0.4355	0.0001
1968	0.5792	0.0001	Area 13–15	0.6432	0.0001
1969	0.3223	0.0001	Area 16–17	0.6098	0.0001
1970	0.5948	0.0001	Area 18–19	0.5995	0.0001
1971	0.4782	0.0001	Area 20–21	0.4557	0.0001
1972	0.4472	0.0001	Area 22–28	0.6285	0.0001
1973	0.2613	0.0001	Depth 1 (inshore)	0.0978	0.0001
1974	0.3107	0.0001	Depth 2 (1–5 fm)	0.1819	0.0001
1975	0.3645	0.0001	Depth 3 (6–10 fm)	0.0502	0.0001
1976	0.3320	0.0001	Depth 4 (11–15 fm)	0.0824	0.0001
1977	0.3358	0.0001	Depth 5 (16–25 fm)	0.0071	0.1227
1978	0.2862	0.0001	Ln(Days fished)	0.9942	0.0001
1979	0.1717	0.0001	Ln(Footrope length)	0.3377	0.0001
1980	0.1337	0.0001	Ln(Vessel length)	0.3146	0.0001

where *FRL* is footrope length, *VL* is vessel length, *CV* denotes the candidate vessel for standardization, and *SV* denotes the standard vessel. If the standard vessel[6] has a *FRL* = 30 yd and *VL* = 55 ft and the candidate vessel has a *FRL* = 48 yd and a *VL* = 65 ft, then the *RFP* can be computed as

$$RFP\ index = \left(\frac{48}{30}\right)^{0.34}\left(\frac{65}{55}\right)^{0.31} = 1.24.$$

Thus, the candidate vessel would be expected to land 24% more shrimp if both vessels were fishing at the same time and in the same location. Since consolidated vessels do not have vessel characteristics recorded, we first estimated the average *RFP* for the documented vessel in a given cell and applied that *RFP* to the consolidated vessels.

Expansion Model Selection

Ideally the form of the expansion model should be similar to the standardization model. In the expansion model, however, much of the data is consolidated and vessel identities are unknown; therefore, vessel characteristic information is unavailable for a portion of the interview landings data set. Consolidated records do, however, distinguish between boats and vessels.[7] In the equation, we considered any U.S. Coast Guard registered vessel ≤60 feet in length as a boat, since that size craft can fish in most state waters.

Several different models (various functions of boat/vessel, area, depth, month, catch per trip, catch per unit effort, price, and dollars per trip) were considered. Interestingly, equations that were not price related had a much higher error sum of squares (on the origional scale) than models that were price related. Shrimpers are commercial fishermen and earn their living by harvesting shrimp that have value; thus, while catch is important in explaining effort, the value or price of shrimp is also very important. Of the price-related models, the following model was judged to be the most appropriate for expansion due to its simplicity and its relatively lower error sum of squares over all years

$$ln(dfpt) = f\{vess, area, depth, month, ln(cpt), ln(price), [ln(price)]^2\} \quad (9)$$

where *dfpt* is days fished per trip. The variables *vess* (boat or vessel), *area* (10 area groups: 1–3, 4–6, 7–9, 10–12, 13–15, 16–17, 18–19, 20–21, 22–28, and ≥29), *depth* (6 depth groups: inshore, 1–5 fm, 1–10 fm, 11–15 fm, 16–25 fm, and ≥26 fm), and *month* (12 months) are included in the model through use of dummy variables. A separate regression equation was estimated for each year (1965–93) for which data were available. Using the fitted model, interviewed effort estimates were calculated as $exp(ln(dfpt))$ and compared with effort data based on actual interviews. The model underestimated the actual days fished as the mean of the log normal distribution $exp(\mu+0.5\sigma^2)$ (Dudewicz and Mishra, 1988; Seber and Wild, 1989). Thus, multiplying the model estimate with a bias correction factor of $exp(s^2/2)$ provided an effort estimate with greater accuracy (Fig. 3). This correction factor accounts for the log transformation.

Expansion Model Validation

Table 3 provides the R-square values for the selected expansion model (discussed above) by year. It also provides the actual total interviewed effort and predicted total interviewed effort, which helps to assess the predictability of the expansion model. The difference between actual and predicted total interviewed effort is expressed as percent of actual total interviewed effort. Examination of Table 3 shows the difference between actual and estimated interviewed days fished to be within 1% for

[6] The average fishing craft (vessel and boat) in 1965 is assumed to be the standard vessel for 1965 and across all years. Since boats are smaller than the standard vessel, their *RFP* in 1965 will be less than 1.0. Conversely, vessels will be larger than the standard vessel, and their *RFP* will be greater than 1.0 in 1965.

[7] Boats are generally smaller craft (from 25 to 60 feet in length) fishing predominately in bays and shallow offshore waters and are not registered with the U.S. Coast Guard. Vessels are generally larger craft (from 60 to 90 feet in length) fishing predominately in offshore waters and registered with the U.S. Coast Guard.

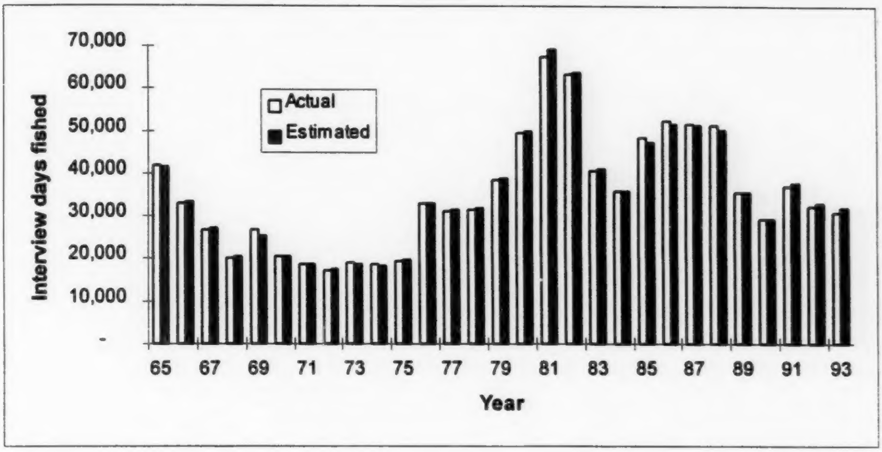


Figure 3.—Actual interviewed days fished vs. adjusted estimated interviewed days fished by year.

Table 3.—The R-square and cross validation of the expansion model.

		Interview days fished		
Year	R-square	Actual	Estimated	% Difference
1965	0.7770	41,858	41,675	–0.44%
1966	0.8169	32,917	33,196	0.85%
1967	0.8174	26,724	27,120	1.48%
1968	0.8140	20,280	20,393	0.56%
1969	0.8001	26,762	25,226	–5.74%
1970	0.8661	20,356	20,419	0.31%
1971	0.8535	18,527	18,640	0.61%
1972	0.8672	17,189	17,461	1.58%
1973	0.8273	18,980	18,707	–1.44%
1974	0.8418	18,599	18,477	–0.66%
1975	0.8696	19,501	19,821	1.64%
1976	0.8803	32,880	33,133	0.77%
1977	0.8576	31,135	31,724	1.89%
1978	0.8457	31,481	31,739	0.82%
1979	0.7762	39,107	39,012	–0.24%
1980	0.7975	49,581	50,106	1.06%
1981	0.8186	67,445	69,308	2.76%
1982	0.8136	63,369	64,060	1.09%
1983	0.8506	40,839	41,198	0.88%
1984	0.8410	35,913	35,790	–0.34%
1985	0.8685	48,380	47,158	–2.53%
1986	0.8521	52,385	51,832	–1.06%
1987	0.8556	51,846	51,231	–1.19%
1988	0.8510	51,182	50,072	–2.17%
1989	0.8098	35,686	35,493	–0.54%
1990	0.8128	29,245	29,144	–0.35%
1991	0.8232	36,948	37,645	1.89%
1992	0.8627	32,151	33,052	2.80%
1993	0.8752	30,926	31,842	2.96%

13 out of 29 years, and within 2% for 23 out of 29 years. Other annual validation comparisons by area, depth, and month are reported in Griffin and Shah.[8]

[8] Griffin, W. L., and A. K. Shah. 1995. Estimation of standardized effort in the heterogeneous Gulf of Mexico shrimp fleet. NOAA, NMFS, MARFIN Contr. Rep. NA37FF0053-01, 50 p.

The actual interviewed effort is predicted with very high precision through the selected expansion model.

Relative Fishing Power

The *RFP* of the average fishing craft (vessels and boats for the total fleet) moved upward from 1.00 in 1965 to 1.23 in 1980, then dropped in 1981 to 1.15 and remained relatively constant through 1988 and then increased again (Fig. 4). This implies that the *RFP* of craft fishing in the Gulf of Mexico shrimp fishery (boats and vessels) in 1980 was 23% more powerful than the standard craft fishing in 1965. In 1993 the relative fishing power was slightly less than that in 1980. The *RFP* of the inshore and offshore fisheries follows the same trend as the total, but the curve is much smoother for the offshore fishing. Comparing the *RFP* between craft that fish inshore and those that fish offshore, we find that craft fishing inshore in 1965 were only 80% as powerful as those fishing offshore. This was still true in 1993.

The drop in 1981 in *RFP* (which remained constant through 1987) can be explained using fuel price and price received for shrimp (Fig. 5). The fuel price began to increase at the end of 1973 and doubled in 1974. At the same time, shrimp prices declined from 1973 to 1974. Shrimpers had a hard time covering cost in 1974 and 1975 (Warren and Griffin, 1980). The fuel price continued to increase, but more slowly, into the beginning of 1979. However, the real shrimp price also increased in 1979 offsetting the increase in the fuel price. As a result, shrimpers invested in new vessels during the profitable years, 1976–78, increasing the *RFP*. During 1979 fuel prices began to rise rapidly, and in 1980 the real shrimp price began to decline from US$5/pound in 1979 to US$2 by 1993. Shrimpers who ordered vessels in 1978 received them in 1979 and 1980; therefore, the *RFP* continued to increase through 1980. Beginning in 1979, shrimpers began to take steps to be more fuel-efficient. Investment in new vessels nearly came to a halt, causing the *RFP* to remain stable through 1987. After 1987, *RFP* increased through 1993, except for 1989; however, this increase was due not to the entry of newer and more powerful vessels into the fishery, but rather, to older and less powerful vessels leaving the fishery. Although the price of fuel declined through 1986, it was not sufficient to generate interest in investing in new shrimp vessels.

Comparison of Estimated Nominal Effort

Figures 6a–c compare our estimates with those of NMFS for total, inshore, and offshore nominal days fished, respectively, by year. Through 1975, our

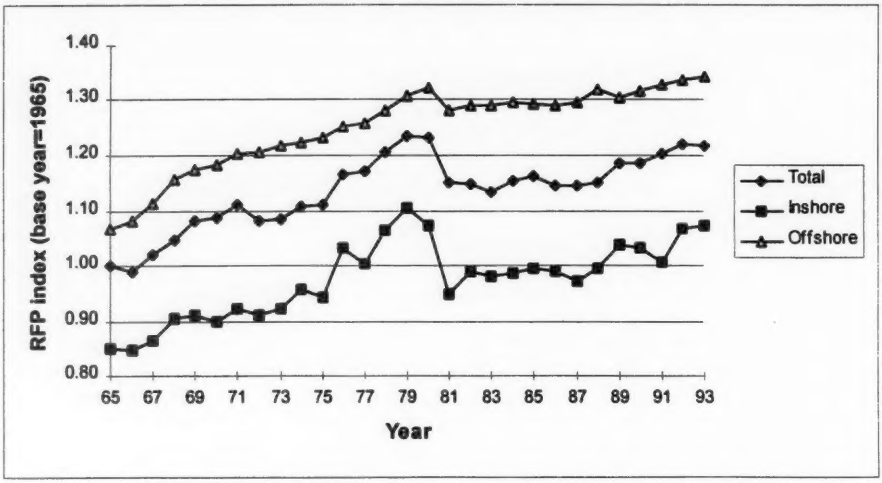


Figure 4.—Change in *RFP* in the total, inshore and offshore shrimp fishery by year.

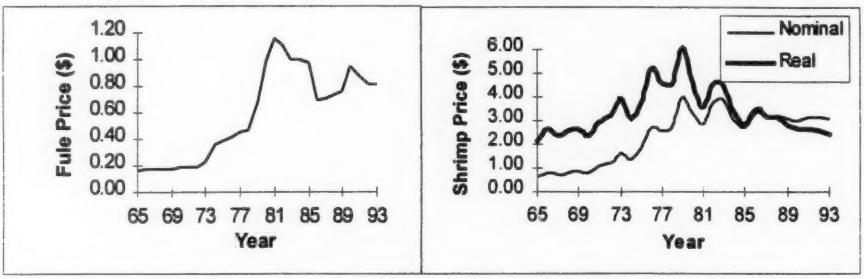


Figure 5.—Price of diesel fuel and average price of shrimp (nominal and real dollars) in offshore shrimp fishery. Real dollars based on the consumer price index (1982–84=100).

estimates of total nominal days fished (Fig. 6a) almost coincide with those of NMFS. After 1975, both estimates have the same trend, but ours are higher for all years except 1979, 1980, and 1992. Inshore (Fig. 6b), estimates coincide through 1971. Beginning in 1981, our estimates of inshore days fished exceed those of NMFS. Offshore estimates (Fig. 6c) by both methods track reasonably well. However, total days fished decreased beginning in 1988, largely due to a decline in the inshore fishery.

The discrepancies between these estimates and those of NMFS may be explained in part by a bias in data obtained by NMFS. Their nominal effort data is generated entirely from interviews obtained by port agents. Therefore, interview bias, including that from selection of craft type by the interviewer, becomes important. In 1965, 72% of inshore shrimp landings came from boats (≤60 ft), and 28% from vessels (> 60 ft and registered by the U.S. Coast Guard). Inshore, agents interview landings were 92% from boats and 8% from vessels. Beginning in 1989, vessels were targeted for interview more frequently than boats, and virtually no boats have been interviewed either inshore or offshore since 1989. Thus, the interview process in itself has introduced a bias in nominal effort data inshore resulting from non-proportionate sampling of the craft types. During the 29 years from 1965 through 1993, interviews with offshore shrimpers have remained at about 20% of the recorded vessels, however.

Standardization of Effort

Figures 7a–c show nominal days fished compared to standard days fished for total, inshore, and offshore shrimp fisheries, respectively. Using 1965 as the base year[9], real effort has increased 165% in the total shrimp fishery from 1965 to 1993, whereas nominal days fished increased only 118%. Thus, taking account of the increased fishing power of the fishing craft, there are 47% more standard days in 1993 than would be suggested by the nominal days fished. Examining the inshore shrimp fishery we find nominal days fished has increased 266% during this time period, whereas standard days increased 361%. Offshore nominal days fished increased 75% and standard days fished increased 120%. This increase in days fished is the actual increase in U.S. waters only.

[9] Choosing the base year is an arbitrary choice. We could just as easily have chosen 1993 instead of 1965. The trend will be the same as will the percentage change in real days fished over time. The absolute magnitudes will differ, however.

Figure 6a.—Comparison of our estimates with the NMFS estimates of total nominal days fished by year.

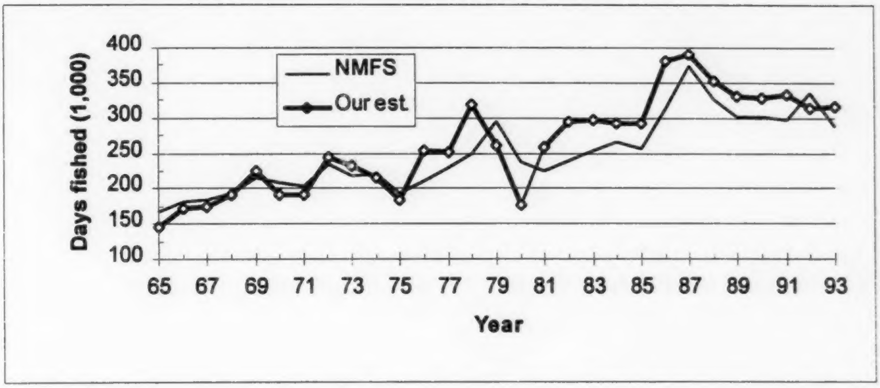


Figure 6b.—Comparison of our estimates with the NMFS estimates of nominal days fished in inshore shrimp fishery by year.

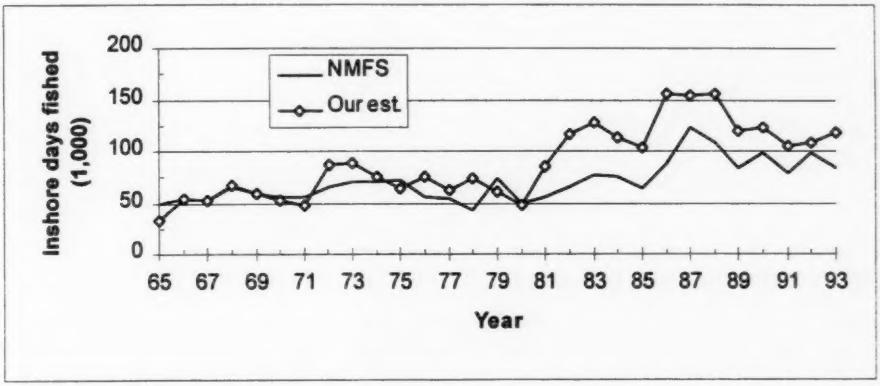
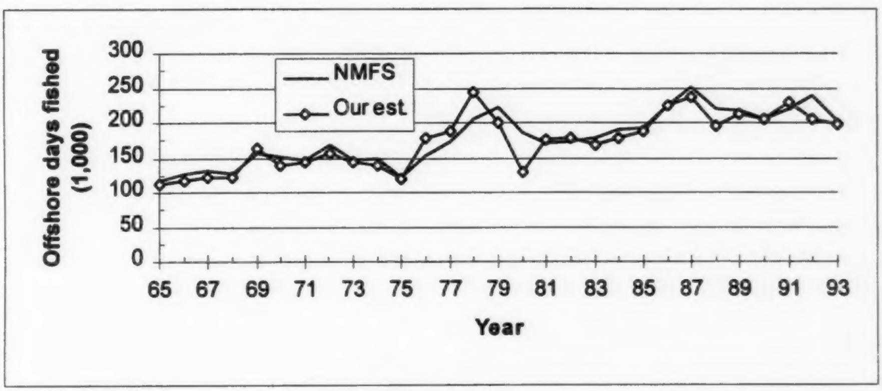


Figure 6c.—Comparison of our estimates with the NMFS estimates of nominal days fished in offshore shrimp fishery by year.



Prior to 1977 when Mexico extended its territorial limits, offshore shrimpers also fished a significant amount of time in Mexican waters (Fig. 8). Therefore, comparing 1993 to 1965, U.S. shrimpers in offshore waters of the Gulf of Mexico increased nominal days fished only 16%. Nominal days fished inshore increased 266% during this same 29-year period, most in Louisiana and Texas (about 315%). In response to the increase in the days fished inshore, the Texas Legislature passed Senate Bill 750, a shrimp license management program with a buy-back option, designed to stop the increase in licenses sold for the bay and bait shrimp fisheries.[10]

[10] Texas sells a commercial shrimp bay license, a commercial shrimp Gulf license, and a bait license.

Figure 7a.—Comparison of percent change in nominal days fished (our estimates) with standard days fished for total U.S. shrimp fishery in the Gulf of Mexico by year.

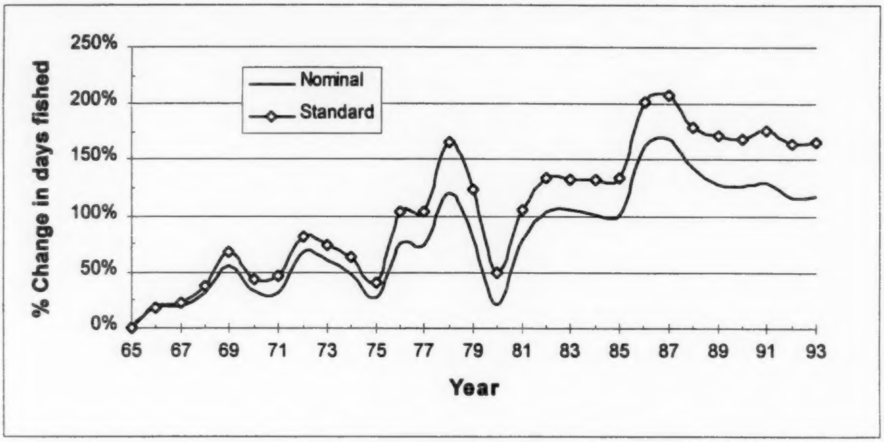


Figure 7b.—Comparison of percent change in nominal days fished (our estimates) with standard days fished for the inshore shrimp fishery in the Gulf of Mexico by year.

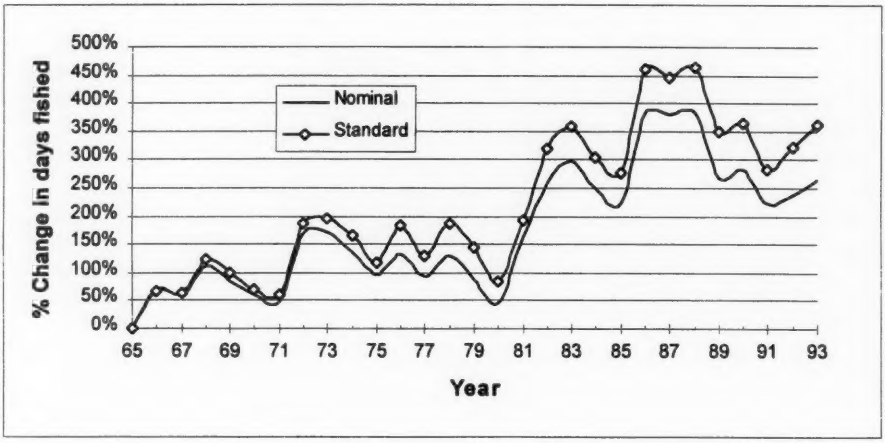
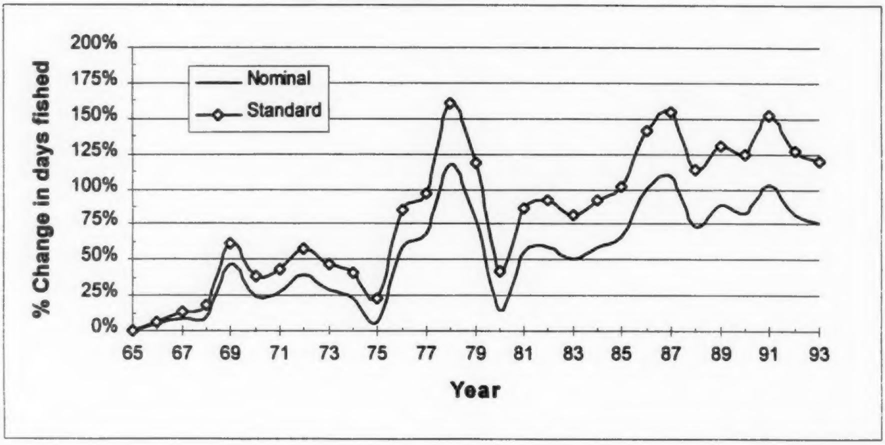


Figure 7c.—Comparison of percent change in nominal days fished (our estimates) with standard days fished for the offshore shrimp fishery in the Gulf of Mexico by year.



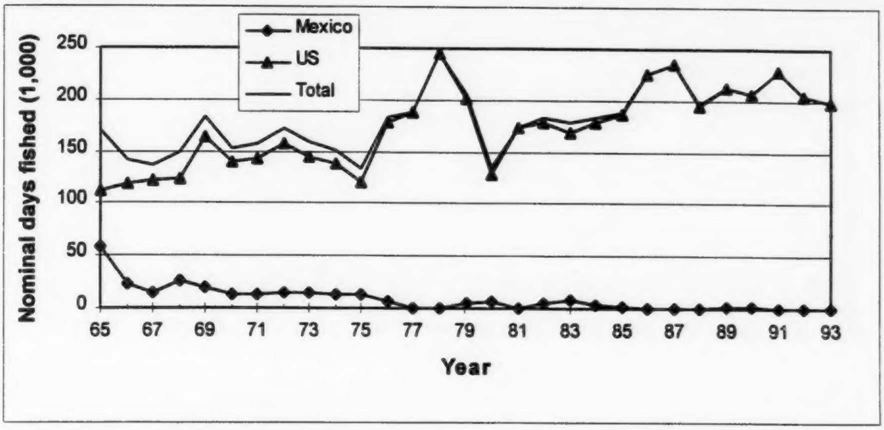


Figure 8.–Nominal days fished (our estimates) in U.S. waters, Mexican waters, and total offshore waters, in the Gulf of Mexico by year.

Conclusions and Recommendation

The modeling approach presented here is a reasonable and logical alternative to the NMFS approach. Our approach eliminates the need for subjectivity in pooling over neighboring cells, in the case of missing cells, to estimate nominal days fished. Since we fit an expansion model for each year, our approach is more sensitive to yearly changes and is more likely to capture these changes. Our approach yields higher inshore days fished in the latter years than does the NMFS due to the reduction in interview landings data in the inshore area. This causes a bias in the NMFS estimates of days fished and most probably in our estimate as well. It is strongly recommended that future data collection by the NMFS be more proportional than what it has been since 1984.

Acknowledgments

We appreciate the excellent cooperation we received from Frank Patella and for the excellent editorial comments from Zoula Zein-Eldin, both of the NMFS Galveston Laboratory. We also appreciate the helpful suggestions we received from John Vondruska and John Ward of the NMFS Southeast Regional Office, and from the anonymous journal reviewers. This work was partially funded under Federal MARFIN Project No. NA37FF0053-1 through the Department of Commerce, NOAA, National Marine Fisheries Service. Research support from Texas Agricultural Experimentation Service is gratefully acknowledged.

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The 1996 U.S. Purse Seine Fishery for Tropical Tunas in the Central-Western Pacific Ocean

ATILIO L. COAN, Jr., GARY T. SAKAGAWA, DOUG PRESCOTT, and GORDON YAMASAKI

Background

Commercial fishing for tropical tunas (yellowfin, *Thunnus albacares*; skipjack, *Katsuwonus pelamis;* and bigeye, *T. obesus*) in the western Pacific Ocean by U.S.-registered purse seiners has been managed according to requirements of the South Pacific Regional Tuna Treaty (SPTT) since June 1988. This treaty is between the United States and 16 Pacific island countries[1]. It provides U.S. tuna purse seiners access to tropical tunas in a 25.9 million km^2 area of the central-western Pacific Ocean (Fig. 1) in exchange for fishing fees and adherence to rules related to closed areas, data reporting, etc. (FFA, 1994; NMFS[2]). The agreement ends in 2003.

Data requirements of the SPTT include reporting of fishery statistics and biological data from the catches. The Southwest Region (SWR) of NOAA's National Marine Fisheries Service (NMFS) is responsible for administering Treaty requirements for the United States and for coordinating with the Forum Fisheries Agency (FFA), Treaty Administrator for the 16 Pacific island countries.

SWR field personnel in American Samoa monitor landings of all licensed vessels, collect fishery statistics, sample the catches, and provide the results to the FFA and the NMFS Southwest Fisheries Science Center (SWFSC). The SWFSC processes the data and transmits the processed data to the FFA on a bimonthly basis. Data involved are records from Regional Purse Seine Logbooks, Unloading Logs, and sizes of fish and species composition from port sampling of landings.

In this report, fishery statistics for the 1996 fishing season are summarized and reviewed along with similar historical data for the fishery. The fishing season used is the calendar year, January–December, which is different from the "SPTT year," 15 June of one year to 14 June of the next year. Because complete 1996 statistics are not yet available, year-end results are extrapolated from 86% of the available statistics to provide a preliminary estimate of 1996 results.

Fishery Monitoring

In 1996, a U.S. fleet of 40 purse seiners fished in the SPTT area and completed a total of 175 fishing trips. Regional Purse Seine Logbooks and Unloading Logs were collected after every trip. Landings were also sampled for sizes of fish and for species composition. Sampling was conducted largely in Pago Pago, American Samoa, where about 94% of the fleet's catch was landed, and to a minor extent in Tinian, Northern Mariana Islands. Over 58,800 tuna (21,200 yellowfin, 24,200 skipjack, and 13,400 bigeye) were examined and fork length (FL) measurements taken by NMFS technicians. Sampling coverage was in accordance with an agreed-upon sampling program (Coan et al.[3]) designed for estimating with statistical accuracy overall species composition of the landings and sizes of each species landed by the fleet.

Yellowfin and bigeye tuna have traditionally been landed combined and recorded in U.S. statistics as "yellowfin tuna" because these species are difficult to separate, especially for small individuals, and cannery prices for both species are identical. Sampling by

[1] Australia, Cook Islands, Federated States of Micronesia, Fiji, Kiribati, Marshall Islands, Nauru, New Zealand, Niue, Palau, Papua New Guinea, Solomon Islands, Tonga, Tuvalu, Vanuatu, and Western Samoa.

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ABSTRACT—The U.S. tropical tuna purse seine fleet has fished the central-western Pacific Ocean under the South Pacific Tuna Treaty since 1988. The 1996 fishery was the poorest since the start of the Treaty. Fishing effort declined due to the financial collapse of a large fishing enterprise. Catches reached record lows for yellowfin tuna, Thunnus albacares, *and skipjack tuna,* Katsuwonus pelamis, *and continued a declining trend that started in 1995. Catch rates also decreased to the lowest levels since 1991. Whether this declining trend in catch rates is due to reduced availability of fish caused by cyclic ocean environmental changes affecting vulnerability or to reduced abundance from excessive fishing pressure is not yet known and needs to be assessed.*

[2] NMFS. 1993. Purse seine fisherman's guide to the South Pacific Tuna Treaty. U.S. Dep. Commer., NOAA Natl. Mar. Fish. Serv., Southwest Reg., 21 p.

[3] Coan, A. L., N. Bartoo, and G. Sakagawa. 1988. Plan for collection of fisheries data from U.S. tuna purse seiners fishing in the South Pacific. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Southwest Fish. Sci. Cent. Admin. Rep., LJ-88-19, 19 p.

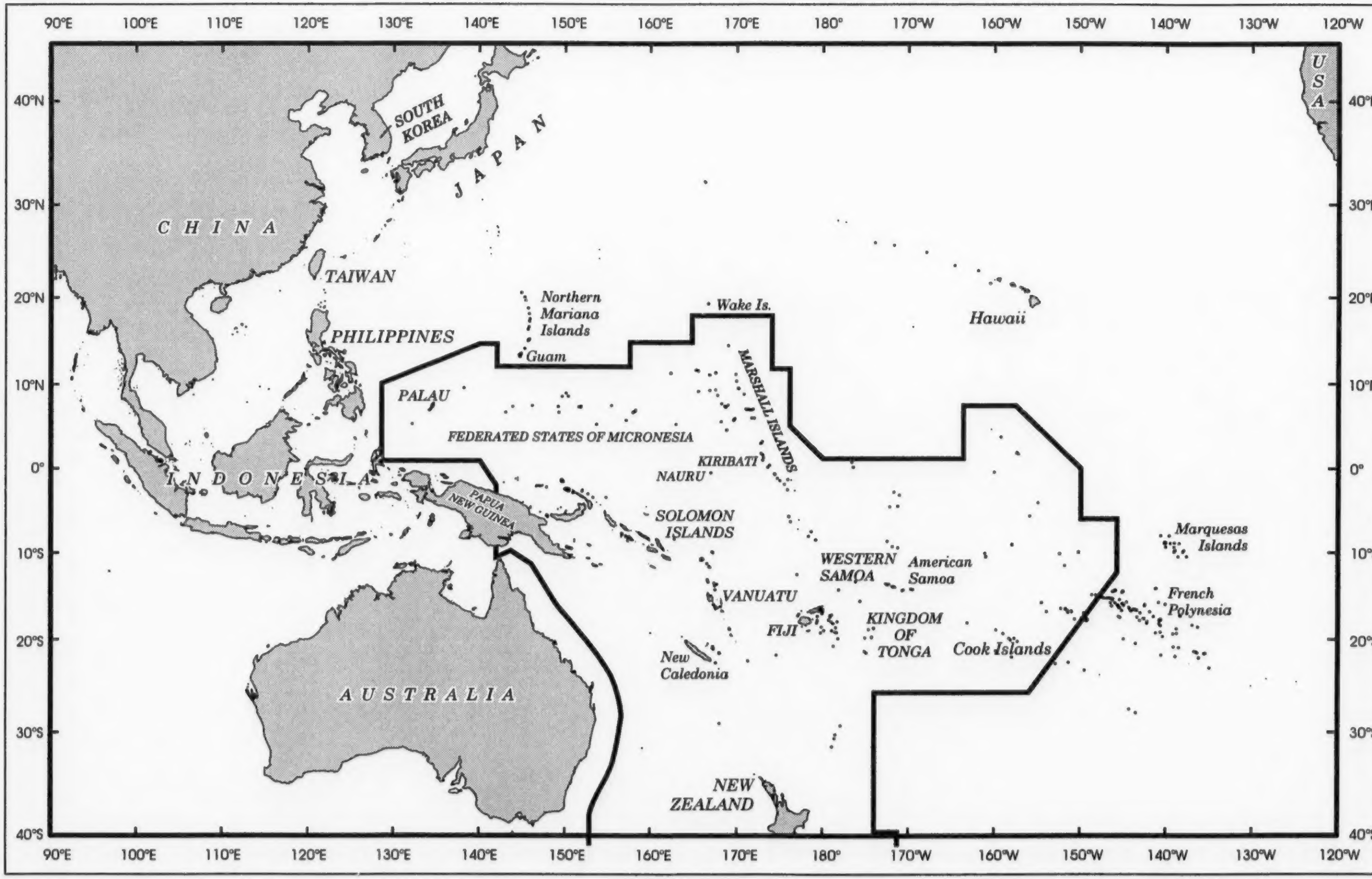

Figure 1.—South Pacific Regional Tuna Treaty (SPTT) area.

NMFS personnel was, therefore, established for accurately determining the species composition in the "yellowfin tuna" landings.

In 1996, canneries in Pago Pago began, for the first time, to separate bigeye tuna from yellowfin tuna and record their landings separately. This practice started in November and has not yet been validated for accuracy. Landings statistics by species from canneries were not used in this report. Instead, data collected solely by NMFS port samplers were used to estimate species composition in "yellowfin tuna" landings. The estimation procedure was similar to that used in the past (Coan et al.[4]) and takes into account differences in species composition between different types of sets and different sizes of fish in the sets.

Fishing Area

During 1996, the U.S. fleet spent 6,038 fishing days in the equatorial belt, extending from about long. 155°W to long. 140°E, which is the traditional fishing zone for the fleet (Fig. 2). Most (75%) of the fishing was conducted in the eastern region, east of long. 160°E, of this zone and in the area between Kiribati and Tuvalu. Traditionally, when fishing is concentrated in this area, catches are primarily from free-swimming, schooling fish, and at most 20% of the sets are on schools associated with floating objects. The 1996 season, however, was an exception; about 41% of the sets were made on floating objects. Furthermore, it appears that this high percentage resulted from increased use of fish aggregating devices (FAD's) by the fleet.

Compared to the 1995 season, the 1996 season was strikingly different. The fleet was about 10% smaller than in 1995 and spent 23% fewer days fishing. Fishing was concentrated in the eastern region, whereas in 1995 it was concentrated in the western region (72%) between Papua New Guinea and Federated States of Micronesia (Fig. 3). Statistics on the number of sets/trip and trips/vessel, on the other hand, were essentially identical for the two years (Table 1). Number of days/trip was about 6% more in 1996 than in 1995, probably because fish schools were harder to find.

Catches

The fleet caught about 126,100 t of tuna in 1996 (Table 2), including 1,400 t of catch discarded at sea. Approximately 56% of this catch was made on schools associated with floating objects and 44% on free-swimming schools. Skipjack tuna was the dominant species in the catch at 100,900 t, or 80% of the total. Skipjack tuna catches were generally high in all months except December (Fig. 4), and high catches were from around Kiribati. Sizes of skipjack tuna landed ranged from 32 cm to 76 cm FL and averaged 51 cm FL (Fig. 5). Fish were slightly smaller, on the average, in catches from schools associated with floating objects (49 cm FL) than from free-swimming schools (53 cm FL).

Yellowfin tuna was second in importance at 16,100 t, or 13% of the total catch. Yellowfin tuna catches were high during January–March and were made mainly off Papua New Guinea (Fig. 4). Average size of yellowfin tuna landed was 64 cm FL, ranging from 32 cm FL to 146 cm FL (Fig. 6). For fish caught in schools associated with floating objects, the average was 59 cm FL and significantly smaller than fish caught in free-swimming schools (average 83 cm FL).

Bigeye tuna made up about 7% of the total U.S. catch, or 9,100 t. Sizes of bigeye tuna ranged from 37 cm FL to 111 cm FL, averaging 58 cm FL (Fig. 7).

Compared to the 1995 season, total catch was down 24%, the lowest since 1988. The skipjack tuna catch declined 24%, yellowfin tuna catch declined 50%, while the bigeye tuna catch increased 184%. This increase in the bigeye tuna catch may be related to the increased use of FAD's, but other factors

Table 1.—Fleet statistics for U.S. tuna purse seiners fishing in the central-western Pacific Ocean.

Year	Vessels: Licensed[1]	Vessels: Fished[1]	Trips	Days/trip	Sets/trip	Trips/vessel
1988	35	31	71	69.25	46.07	2.29
1989	35	35	154	57.96	41.88	4.40
1990	51	43	181	47.32	34.79	4.21
1991	48	43	229	42.38	40.39	5.33
1992	44	44	212	46.23	35.09	4.82
1993	42	42	199	51.92	37.28	4.74
1994	48	49	239	44.22	35.51	4.88
1995	47	44	206	49.14	33.39	4.68
1996[2]	34	40	175	51.93	34.21	4.38

[1] The number of vessels that fished can be different from the number of licensed vessels, since vessels are licensed from 15 June of one year to 14 June of the next year, whereas any vessel fishing in a calendar year is recorded as fished.

[2] Data for 1996 are preliminary.

Table 2.—Catches (t) and catch rate (t/day fished) for U.S. tuna purse seiners fishing in the central-western Pacific Ocean.

Year	Catch: Yellowfin	Catch: Skipjack	Catch: Bigeye	Catch: Total	Catch rate: Yellowfin	Catch rate: Skipjack	Catch rate: Total
1988	18,832	93,636	1,948[1]	114,416	3.01[1]	15.37[1]	18.38[1]
1989	42,886	95,027	2,421	140,334	7.26	14.59	21.85
1990	52,089	110,044	1,762	163,895	8.91	16.66	25.57
1991	37,330	177,389	1,550	216,269	5.70	24.78	30.48
1992	43,693	155,898	3,480	203,071	6.39	21.48	27.87
1993	46,011	148,419	3,731	198,161	6.46	18.29	24.75
1994	56,426	151,486	1,711	209,623	7.63	18.61	26.24
1995	31,845	132,518	3,190	167,553	4.68	17.39	22.07
1996[2]	16,070	100,945	9,075	126,090	3.42	12.92	16.34

[1] Estimated from data for 6 months (June–December 1988).

[2] Data for 1996 are preliminary.

[4] Coan, A. L., G. Sakagawa, and D. Prescott. 1995. Bigeye tuna catch in the U.S. tuna purse seine fishery of the central-western Pacific. Fifth meeting of the Western Pacific Yellowfin Tuna Research Group, August 21–23, 1995, Noumea, New Caledonia, WPYRG5/6, 11 p.

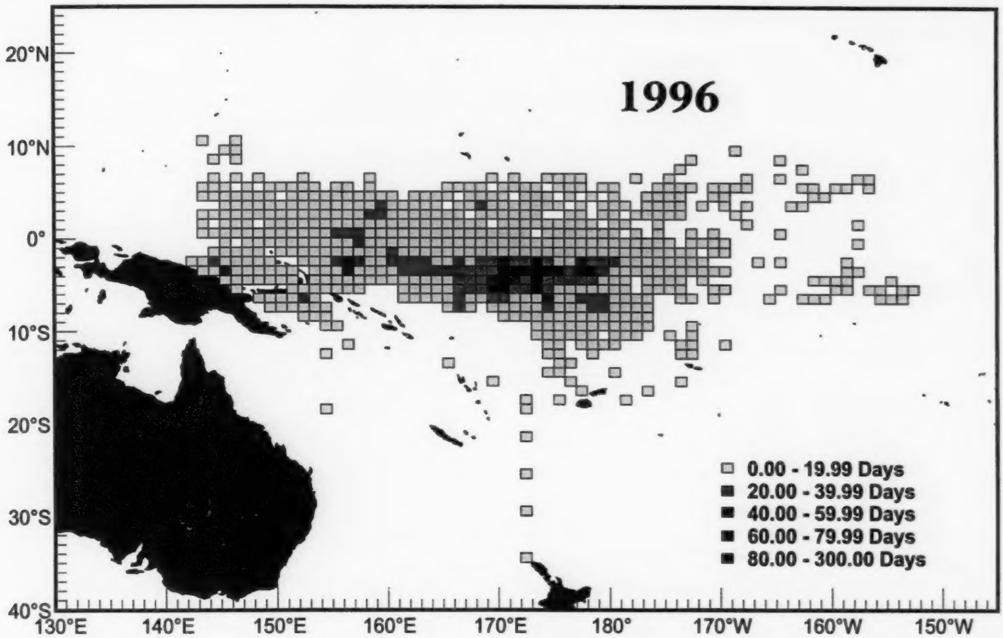

Figure 2.—Distribution of fishing effort (days fished) for U.S. tuna purse seiners fishing in the central-western Pacific during 1996.

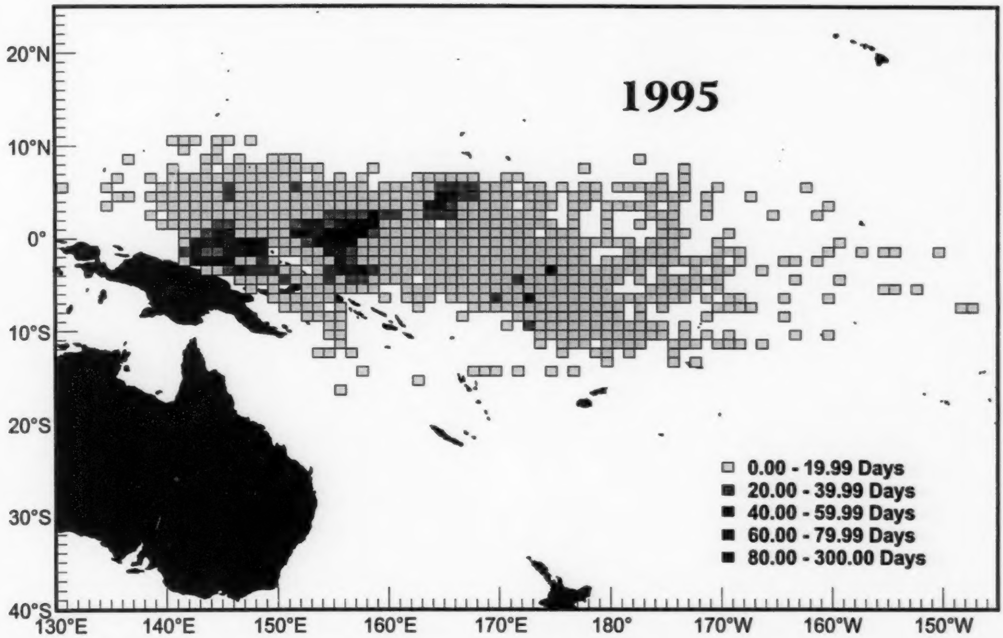

Figure 3.—Distribution of fishing effort (days fished) for U.S. tuna purse seiners fishing in the central-western Pacific during 1995.

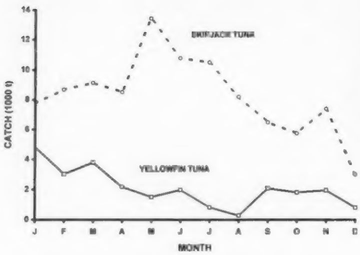

Figure 4.—Monthly catches of yellowfin and skipjack tunas from the 1996 U.S. tuna purse seine fishery in the central-western Pacific.

may also be involved. A comprehensive analysis of this increase has not yet been undertaken.

Pago Pago was the primary destination for the catch in 1996 (Fig. 8). About 94% of the total catch was landed in Pago Pago and the rest in ports of Papua New Guinea (4%, Wewak, Kavieng, Rabaul), Guam/Northern Mariana Islands (1%), Solomon Islands (1%, Honiara), and New Zealand (0.1%, Port Lincoln). Canneries in American Samoa utilized about 85% of the catch, and the rest (15%) was exported to other canneries in the Pacific region as well as to canneries in Puerto Rico and Turkey.

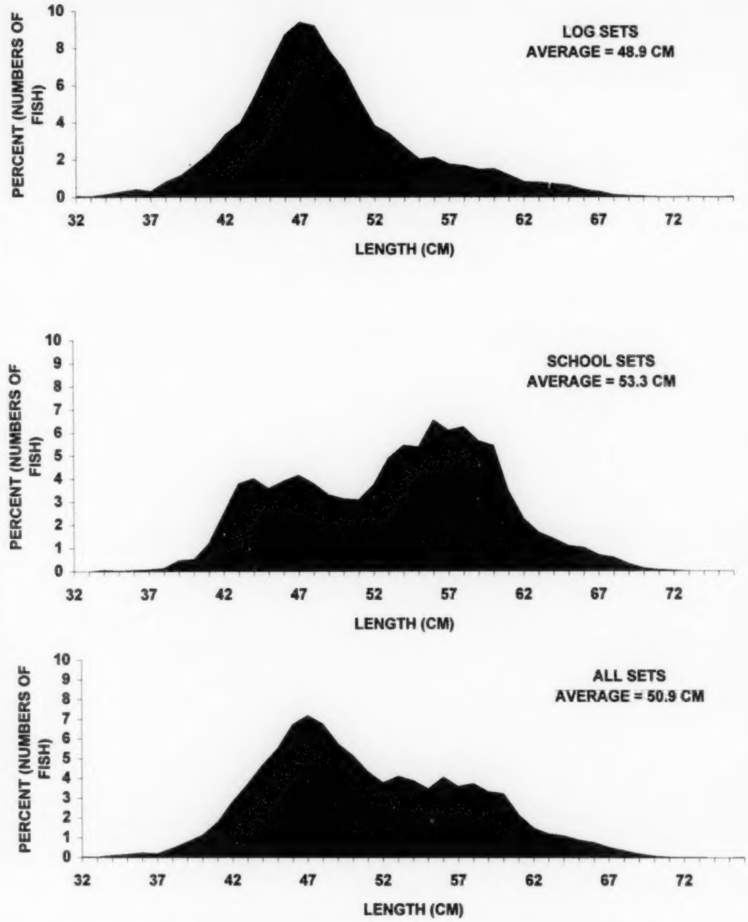

Figure 5.—Length distributions, by set type, of skipjack tuna caught by U.S. tuna purse seiners fishing in the central-western Pacific during 1996.

By-catch and Discards

The practice of reporting by-catches and discards is becoming more routine for the fleet. In 1996, about 75% of the trips reported by-catch and/or discard information. The data were tabulated using species and species groups reported in the logbooks. For convenience, the species were grouped under four large categories: Tunas, Billfishes, Sharks, and Others[5] (Table 3). Under this scheme, tunas, by far, made up the largest share (92% by weight) of reported by-catch and discards, with skipjack tuna the dominant species. This discard represented 1.1% of the retained tuna catch and was rejected largely because the fish were too small for the targeted market. Sharks, at 5% of the reported by-catch, were next in importance, followed by others with 2%, and billfishes with less than 1%.

Catch Rates

Overall catch rate in 1996 was 16.3 t/day fished (Table 2). The rate for yellowfin tuna was 3.4 t/day fished and for skipjack tuna, 12.9 t/day fished. This overall rate is similar to that recorded for other tropical tuna purse seine fisheries, such as 15 t/day fished in the eastern tropical Pacific (IATTC, 1997), 14 t/day fished in the eastern tropical Atlantic (Ariz et al., 1995; Hallier and Diouf, 1995), and 21 t/day fished in the western Indian Ocean (Seychelles Fishing Authority, 1996). The western Pacific fishery, however, is dominated by skipjack tuna catches, whereas the other fisheries are dominated by yellowfin tuna catches. Hence, they are not equally comparable.

Compared to catch rates of past years, the overall 1996 rate continued the decreasing trend that began in 1992 (Table 2). The decline was 40% for yellowfin tuna and 48% for skipjack tuna from the 1991 catch rates. Catch rates in 1996 were significantly below the long-term (1988–95) averages of 6.3 t/day fished for yellowfin tuna and 18.4 t/day fished for skipjack tuna.

[5] In the "Others" category, rainbow runner, *Elagatis bipinnulatus*, and bait fishes such as mackerels (Scombridae), triggerfishes (Balistidae), Pacific bonito, *Sarda chiliensis*, etc., were dominant species.

Table 3.—By-catch and discards from logbooks maintained by U.S. tuna purse seiners fishing in the central-western Pacific Ocean in 1996.

Species	Weight (t)	No. of fish[1]
Tunas (92% by wt.)	73.71	
Skipjack	1,253.50	
Yellowfin	19.32	
Bigeye	2.70	
Skipjack/yellowfin	68.71	
Yellowfin/bigeye	0.09	
Billfishes (0.5% by wt.)		
Black marlin	2.98	
Blue marlin	1.91	
Marlin	2.19	
Sailfish	0.04	
Striped marlin		1
Swordfish		1
Sharks(5% by wt.)	77.93	
Others (2% by wt.)		
"Baitfish[2]"	12.80	
Bat ray		1
Kingfish	0.01	
Mackerel	1.25	
Mackerel/shark[3]	0.09	
Mahi mahi	0.68	
Manta ray	0.07	
Rainbow runner	17.58	
Rainbow runner/shark[3]	0.58	317
Shark/"Baitfish[3]"	1.02	
"Trash fish[4]"	0.07	
Triggerfish	0.26	
Triggerfish/shark[3]	0.53	
"Mixed fish[4]"	0.78	
Wahoo	0.06	
Rainbow runner/triggerfish	0.06	
Rainbow runner/triggerfish/shark[3]	0.16	

[1] "No. of fish" reported is exclusive of those listed under "weight."
[2] Such as mackerels, bonitos, and others.
[3] Sharks were sometimes combined with other species and were reported in different categories since they could not be separated.
[4] The exact species included in these categories is unknown.

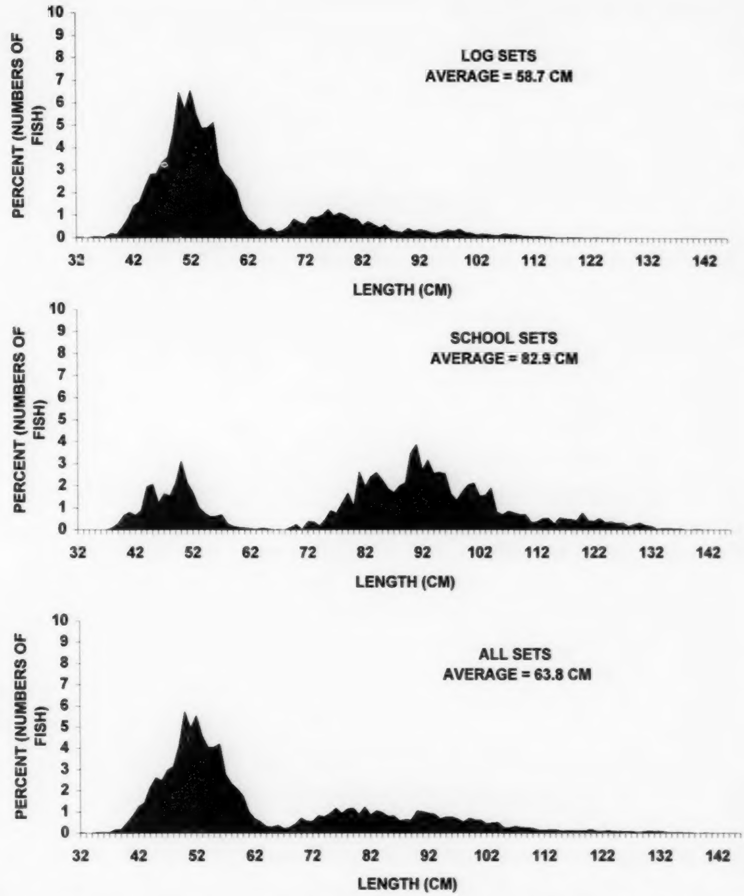

Figure 6.—Length distributions, by set type, of yellowfin tuna caught by U.S. tuna purse seiners fishing in the central-western Pacific during 1996.

Performance

The U.S. fishery was adversely affected by a number of events in 1996 and recorded one of its poorest seasons. Most significant of the events was the financial collapse of a large tuna fishing enterprise that operated 12 licensed vessels and one freezer facility on Tinian (Platt, 1996). The result was a significant decrease in fishing effort and catch for the fishery owing to a withdrawal of about 11 licensed vessels in mid-year. This collapse is likely to have a lasting effect well beyond the 1996 season.

Another adverse event was the reduced availability of fish. The fleet continued to experience declining overall catch rates, with 1996 producing the poorest rate since the start of the SPTT agreement. The highest rate recorded by the fishery was 30.5 t/day fished in 1991. Since then the rate has declined, falling 46% to 16.3 t/day fished in 1996. Whether this declining trend is due to reduced availability of fish owing to cyclic ocean environmental changes affecting vulnerability or to reduced abundance from excessive fishing pressure is not yet known. In the past, scientific evidence has shown that the stocks were moderately exploited and able to sustain current catch levels (SPC[6]). Nonetheless, the fleet struggles to remain profitable and new fishing procedures, such as use of FAD's to improve catch rates, are being more widely used.

Although 1996 was a poor season for the U.S. fleet, the U.S. fishery remained an important source of tuna production for the region and the U.S. market. The catch represented about 14% of the total tropical tuna catch from the western Pacific Ocean, not counting the production of fisheries in Indonesia and the Philippines. It also contributed about 49% of the raw material needs of U.S. canners in 1996 for a production of 27.4 million standard cases of canned light meat tuna.

Acknowledgments

We wish to thank the U.S. captains and cannery personnel for their cooperation and assistance during the 1996 season in the collection and reporting of fishery statistics. Their efforts made it possible for NMFS to complete re-

[6] SPC. 1996. Status of tuna stocks in the western and central Pacific Ocean. Ninth Standing Committee on Tuna and Billfish, 22–23 July 1996, Noumea, New Caledonia. Work. Pap. 3, 37 p.

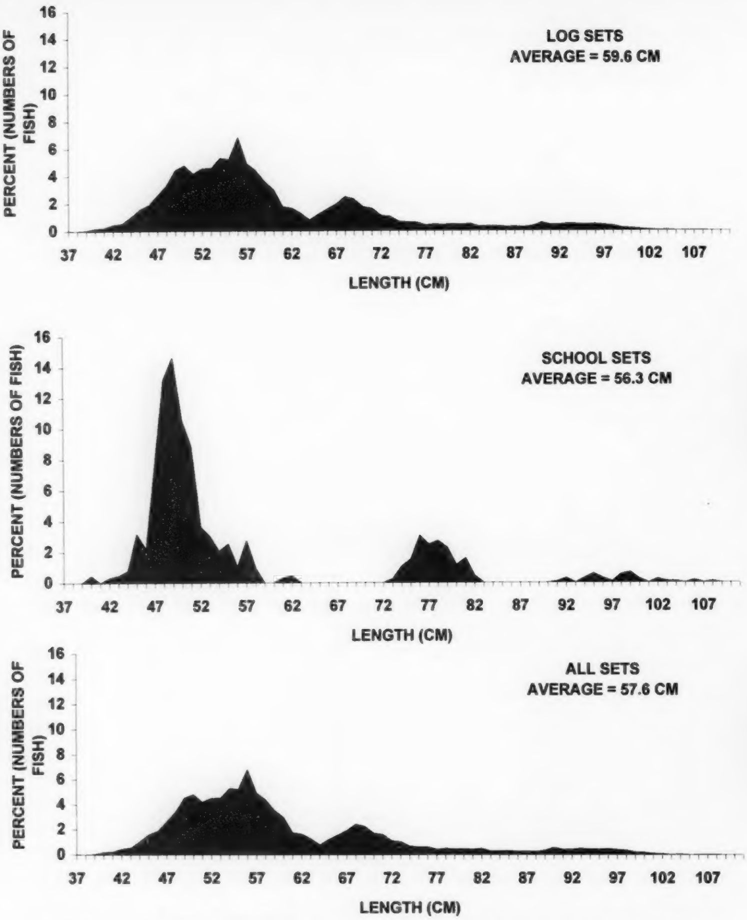

Figure 7.—Length distributions, by set type, of bigeye tuna caught by U.S. tuna purse seiners fishing in the central-western Pacific during 1996.

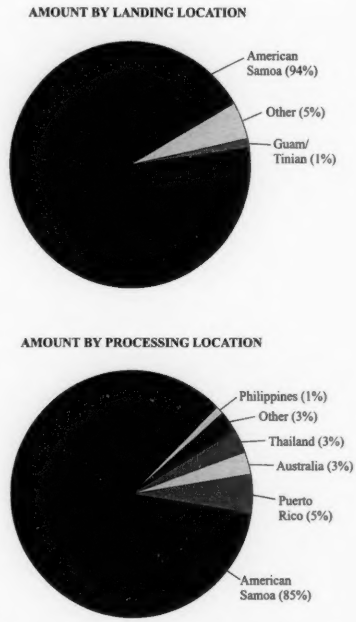

Figure 8.—Locations of landings and processors of catches from U.S. tuna purse seiners fishing in the central-western Pacific during 1996.

quirements of the SPTT agreement and to document the performance of the fishery. The cooperation of the FFA staff is also acknowledged and appreciated.

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An Observed Entanglement of *Lagenorhynchus obliquidens* in the High Seas Driftnet Area in the North Pacific

S. A. MIZROCH and C. HUTCHINSON

Introduction

In 1978, the Japanese High Seas Squid Driftnet Fishery began in the North Pacific, and in 1979 and 1980, the Republic of Korea and Taiwan began their own driftnet fisheries in the same region (Yatsu et al., 1993). The High Seas Squid Driftnet Fishery expanded rapidly in the 1980's, and concern grew that bycatch from this fishery was having a large impact on populations of marine mammals, birds, and salmon (Hobbs and Jones (1993) provide an overview of the fishery). In 1991, due to concern about bycatch, the United Nations General Assembly adopted a resolution which called for a ban on high-seas driftnet fishing effective 31 December 1992.

In 1991, the National Marine Mammal Laboratory of the NMFS Alaska Fisheries Science Center initiated a multidisciplinary research cruise to study the distribution and density of bycatch species taken in the High Seas Squid Driftnet Fisheries. A series of studies on oceanographic conditions, fish, seabirds, and marine mammals was undertaken on the R/V *Acania*, a 126-ft (38.2 m) chartered vessel. The cruise consisted of three separate legs, beginning in Homer, Alaska, on 7 July and ending in Honolulu, Hawaii, on 6 September. Major areas surveyed were between lat. 40°–45°N and long. 155°–170°W on Leg 1, and lat. 43°–45°N and long. 175°W–175°E on Legs 2 and 3.

Line transect data on marine mammal distribution were collected in conjunction with fish, seabird, and oceanographic studies. Gear used included an Isaacs-Kidd midwater trawl net, bongo net, Conductivity-Temperature-Depth

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ABSTRACT—In August, 1991, an entanglement event was observed in the High Seas Driftnet area in the North Pacific. This description of an entanglement of Lagenorhynchus obliquidens *is the first such documented report of dolphins entangling while bowriding. One of the entangled dolphins was rescued from the driftnet.*

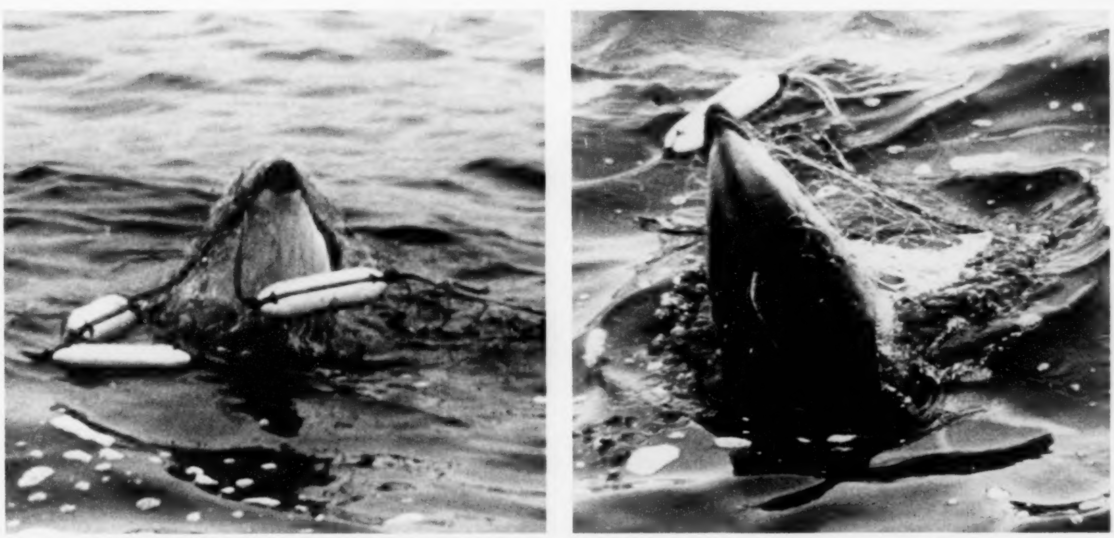

Figure 1.—Entangled *Lagenorhynchus obliquidens* lifting its head and blowhole above the water to breathe. Photographs taken by S. Mizroch, 15 August 1991, at lat. 44°21.3'N, long. 177°45.0'W.

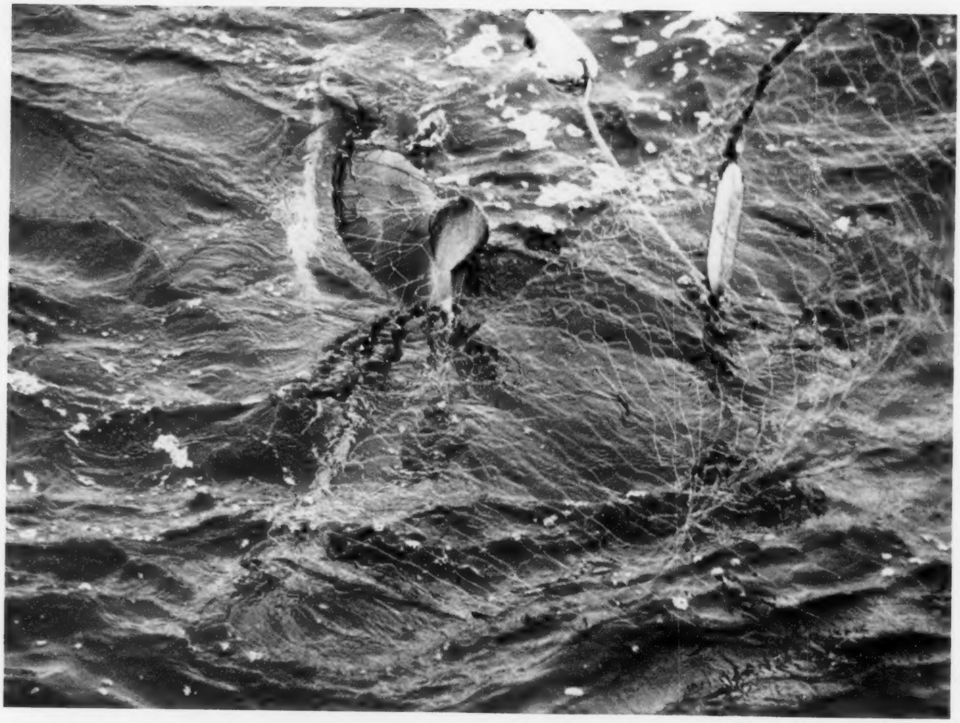

Figure 2.—(Facing pages) A series of photographs of a *Lagenorhynchus obliquidens* entangled in a driftnet. Note the cut on the trailing edge of the dorsal fin in the photograph on the bottom right. Photographs taken by S. Mizroch, 15 August 1991, at lat. 44°21.3'N, long. 177°45.0'W.

(CTD) probes, Expendable Bathythermograph (XBT), and a sea surface temperature recorder. Because the studies were conducted in the High Seas Driftnet Fishery area during the fishing season, before setting our daily north-south transect lines, we would observe the nets being set on east-west lines the night before, and would lay out north-south transect lines to avoid crossing any net lines.

Observations

On 15 August 1991, at 0923 h, lat. 44°21.3'N, long. 177°45.0'W, while on a standard line transect watch, a large mixed group of *Lagenorhynchus obliquidens* and *Lissodelphis borealis* was spotted at a distance of about 900 m. The group included about 200 *L. obliquidens* and 60 *L. borealis*.

As the vessel's cruise track headed in the direction of the large group, small groups of *L. obliquidens* arrived at the bow on both sides of the vessel, with about four or five individuals bowriding at a time. Groups of two or three were approaching along the sides. At 0933 h, while Hutchinson was on watch, the boat crossed a driftnet with about six *L. obliquidens* bowriding. As soon as the boat crossed the net, all but one bowriding dolphin dropped out of sight. It seemed possible at the time that some of the bowriding animals could have become entangled in the net.

When the vessel turned and we arrived at the location of the break in the net at 1000 h, we saw no free-swimming dolphins in the area, but we did see one entangled animal poke its head up to breathe (Fig. 1). The crew lifted the net with long poles that had hooks on one end. The plan was to bring the animal aboard to disentangle it. However, as the net was lifted, the animal was able to twist and turn and free itself. The entire disentanglement effort took less than 5 minutes. There was some blood on the animal from net cuts (Fig. 2), but the animal seemed vigorous when freed from the net, and left with no netting attached.

After the animal was released, we remained in the area of the break to see if any other animals were entangled and took above-water videotape of the driftnet on both sides of the break. We were unable to examine the entire net which was being actively fished at the time.

Upon later review of the videotape taken while we searched for other entangled dolphins, we noticed dips in the net's corkline that may have indicated as many as two other entangled dolphins, although there were no signs of movement in either of these areas. The dips could have also indicated some other nonmammal catch.

Kasuya and Miyazaki (1976) report epimeletic behavior in *L. obliquidens*, when they observed a carcass that was held afloat through the actions of at least one, and perhaps two other *L. obliquidens*. The animal remained by the carcass until the carcass was hooked by the research vessel, at which time the *L. obliquidens* swam away. Based on decomposition of the carcass, they surmised that the animal may have died the preceding day, but they did not know whether the carcass had been accompanied since death or was found by the other *L. obliquidens* after death.

Weinrich (1996) observed an entanglement of *Lagenorhynchus acutus* in the North Atlantic, and noted that the nonentangled dolphins left the area immediately, with no attempt to aid the entangled one (i.e. no evidence at all of epimeletic behavior).

It is unknown whether and how often *Lagenorhynchus* will exhibit epimeletic behavior during interactions with fishing gear. In the case described here and in Weinrich (1996), it appeared that the free-swimming accompanying dolphins did not remain in the area to provide aid to the animal that was entangled in the net. In Kasuya and Miyazaki (1976), the *L. obliquidens* that had been observed accompanying the carcass left as soon as humans intervened.

Acknowledgments

The authors wish to thank R. Hobbs, Head Scientist, for his planning and logistical support during the cruise. We thank D. DeMaster, P. Gearin, M. Gosho, S. Hill, D. Rice, and B. Sinclair for their thoughtful review of this manuscript. We also thank the captain and crew of the R/V *Acania*, R. Harelstad, L. Lohse, G. Lohse, D. Carter, and S. Jones, and the scientific team on Leg 2, B. Ebberts, J. Gerwin, K. Sax, and A. Snyder.

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Editorial Guidelines for the *Marine Fisheries Review*

The *Marine Fisheries Review* publishes review articles, original research reports, significant progress reports, technical notes, and news articles on fisheries science, engineering, and economics, commercial and recreational fisheries, marine mammal studies, aquaculture, and U.S. and foreign fisheries developments. Emphasis, however, is on in-depth review articles and practical or applied aspects of marine fisheries rather than pure research.

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Submission of a manuscript to *Marine Fisheries Review* implies that the manuscript is the author's own work, has not been submitted for publication elsewhere, and is ready for publication as submitted. Commerce Department personnel should submit papers under a completed NOAA Form 25-700.

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Keep titles, heading, subheadings, and the abstract short and clear. Abstracts should be short (one-half page or less) and double-spaced. Paper titles should be no longer than 60 characters; a four- to five-word (40 to 45 characters) title is ideal. Use heads sparingly, if at all. Heads should contain only 2-5 words; do not stack heads of different sizes.

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In style, the *Marine Fisheries Review* follows the "U.S. Government Printing Office Style Manual." Fish names follow the American Fisheries Society's Special Publication No. 12, "A List of Common and Scientific Names of Fishes from the United States and Canada," fourth edition, 1980. The "Merriam-Webster Third New International Dictionary" is used as the authority for correct spelling and word division. Only journal titles and scientific names (genera and species) should be italicized (underscored). Dates should be written as 3 November 1976. In text, literature is cited as Lynn and Reid (1968) or as (Lynn and Reid, 1968). Common abbreviations and symbols such as mm, m, g, ml, mg, and °C (without periods) may be used with numerals. Measurements are preferred in metric units; other equivalent units (i.e., fathoms, °F) may also be listed in parentheses.

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